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REPORT NO.

~~C O N F I D E N T I A L~~

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NAVAER

A MEANS OF COMPARING FIGHTER EFFECTIVENESS IN THE APPROACH PHASE

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DR ~~REPORT NO.~~ 1150

Navy Dept. October 1949, 62p. BuAer

Prepared by Abraham Hyatt
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223 596

C O N F I D E N T I A L

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* Figures 12 through 21 (overlays) are enclosed in envelope attached to inside back cover and labeled p. 63.

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Table of Contents (Cont'd)

SUMMARY

A measure has been devised for comparing the effectiveness of fighters in the approach phase of a fighter bomber encounter. The approach phase is defined as the portion of the flight between the instant of detection of the bomber by the fighter and the instant that the fighter begins firing. If the relative fire control and fire power between fighter and bomber is the same as between fighters and bombers of ~~World War~~ WW II; if the tactics between fighters and bombers are the same as ~~World War~~ WW II; and if the relative training of the crews is the same, then the effectiveness as determined in this report may be compared with the effectiveness, in terms of relative combat losses, of ~~World War~~ WW II fighters against ~~World War~~ WW II bombers.

The "effectiveness measure" of a fighter of the German FW190 type against a B17 flying at 200 ~~knots~~ kt at 23,000 ~~feet~~ ft was determined. This constitutes the base of comparison and was assigned an "effectiveness measure" of unity.

The following six charts, ~~Figures 1 through 6,~~ are presented showing the "effectiveness measure" of six presently operational or prototype aircraft (P51-H, F4U-5, XP80-A, XF2-H, F86-A and XF7-U) when compared to the World War II base. Effectiveness measures versus bomber speed for several altitudes are plotted.

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FIG I

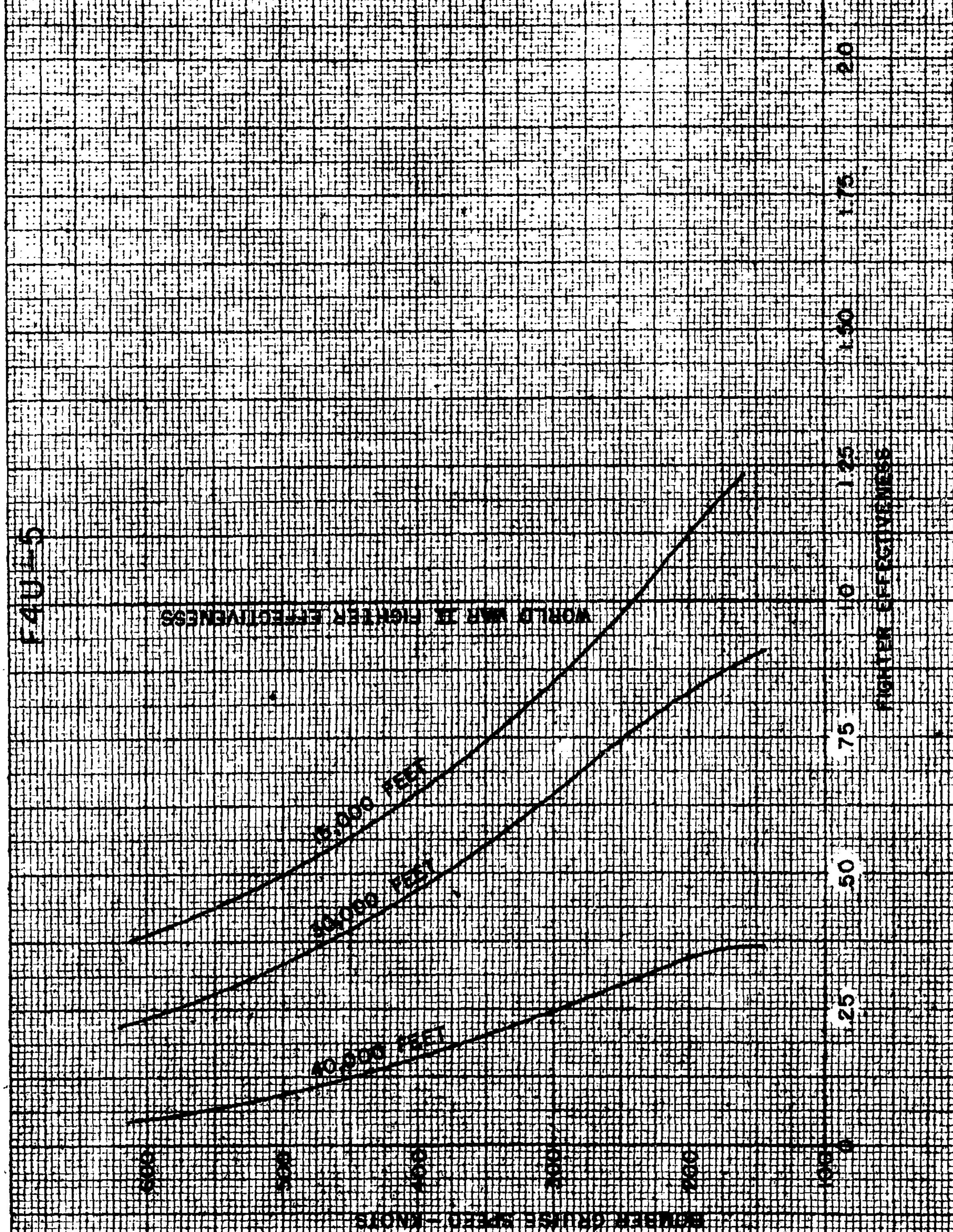

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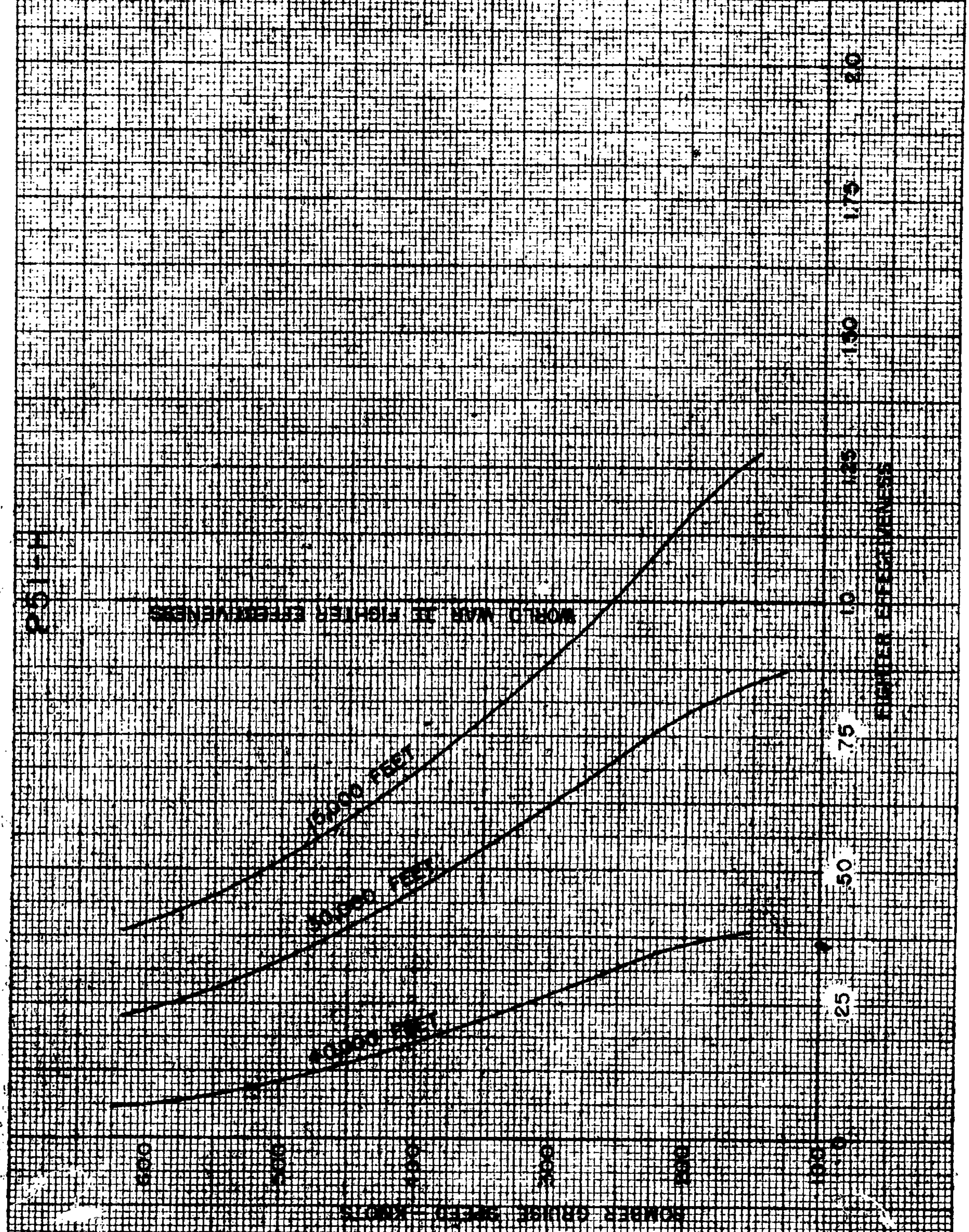
FIG. 2



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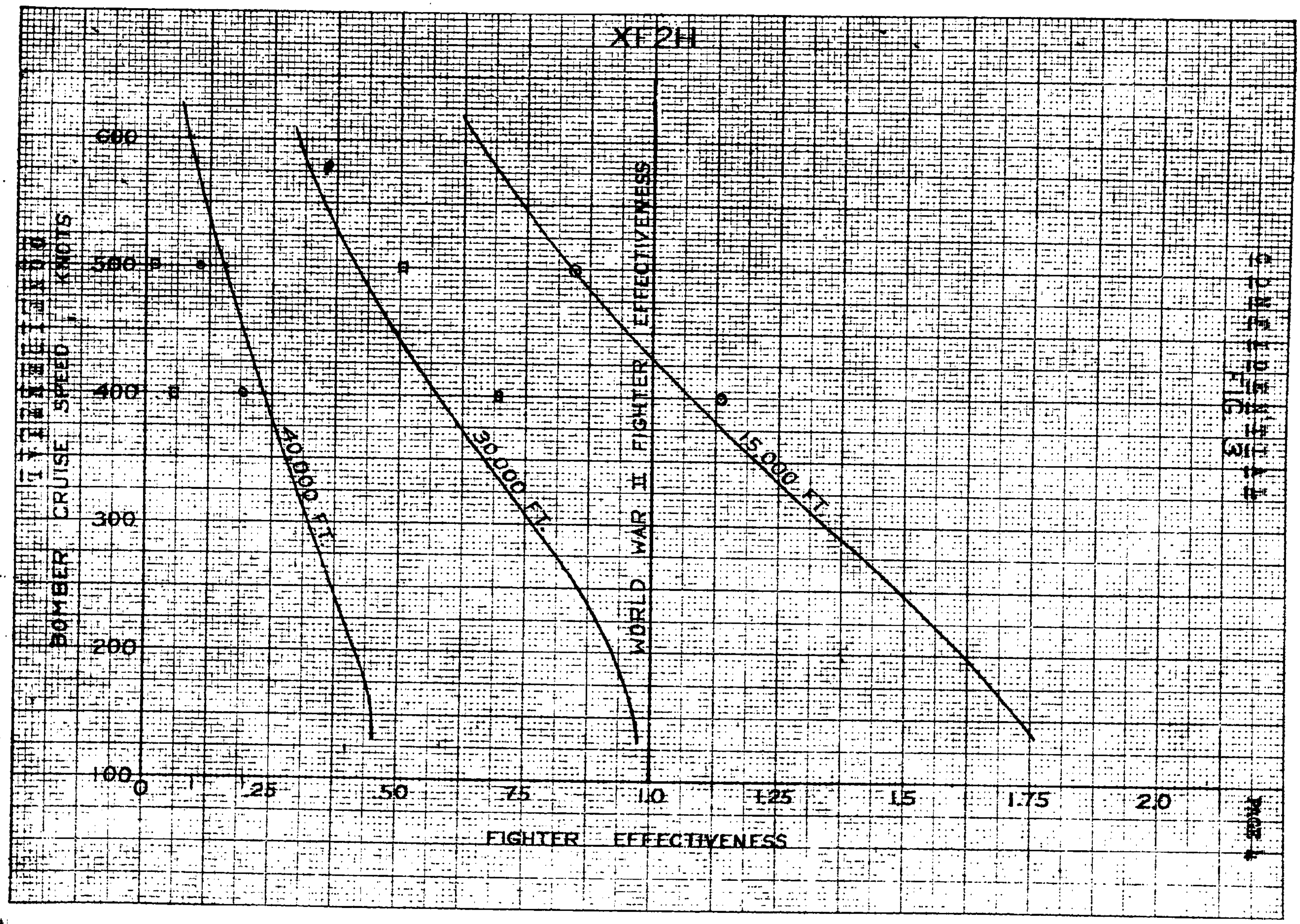
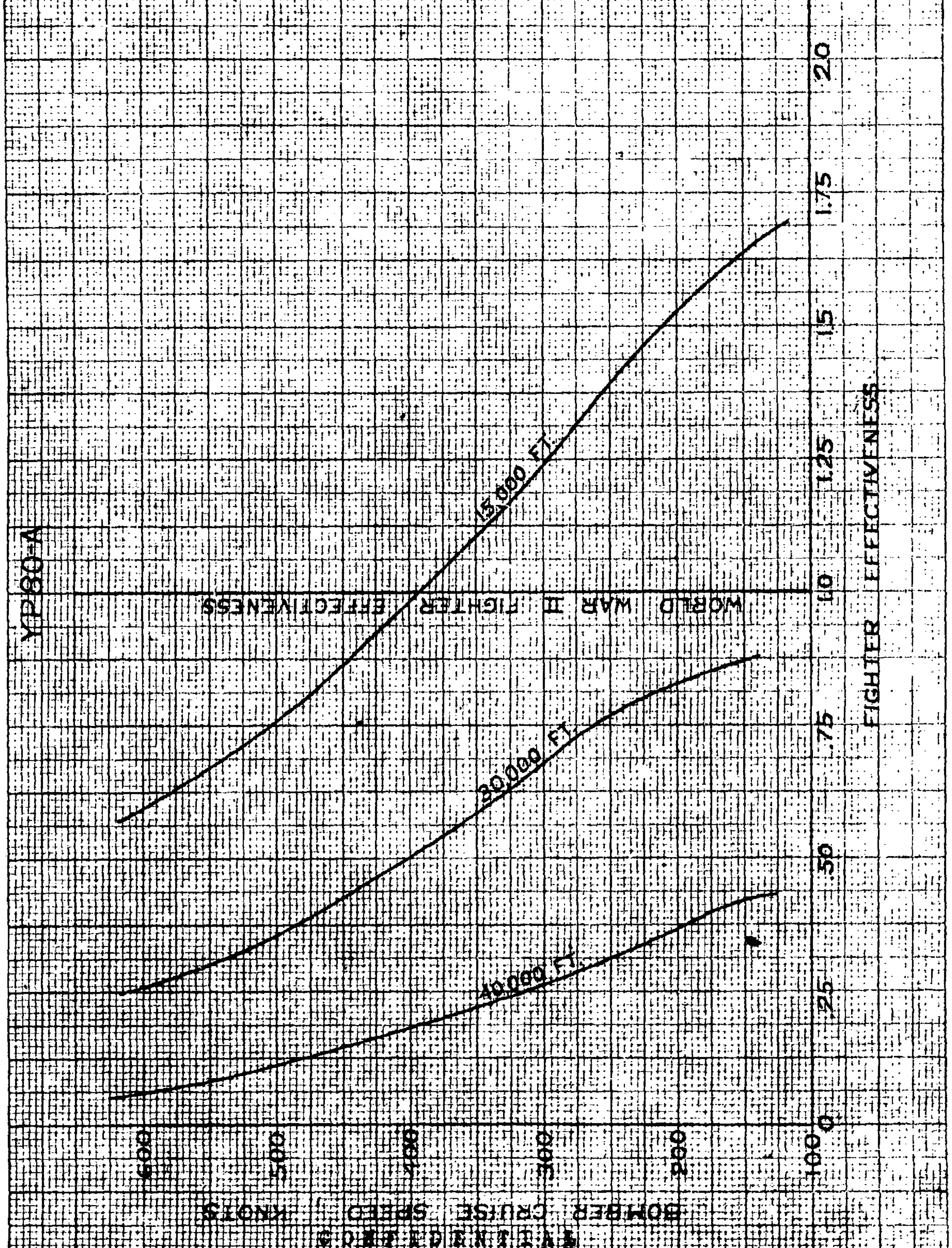

XF2H
BOMBER CRUISE SPEED, KNOTS
600
500
400
300
200
100
0
.25
.50
.75
1.0
1.25
1.5
1.75
2.0
FIGHTER EFFECTIVENESS
40,000 FT.
30,000 FT.
15,000 FT.
WORLD WAR II FIGHTER EFFECTIVENESS

FIG. 4


YP-80-A
15,000 FT.
30,000 FT.
40,000 FT.
WORLD WAR II FIGHTER EFFECTIVENESS
FIGHTER EFFECTIVENESS
0
.25
.50
.75
1.0
1.25
1.5
1.75
2.0
BOMBER CRUISE SPEED KNOTS
100
200
300
400
500
600

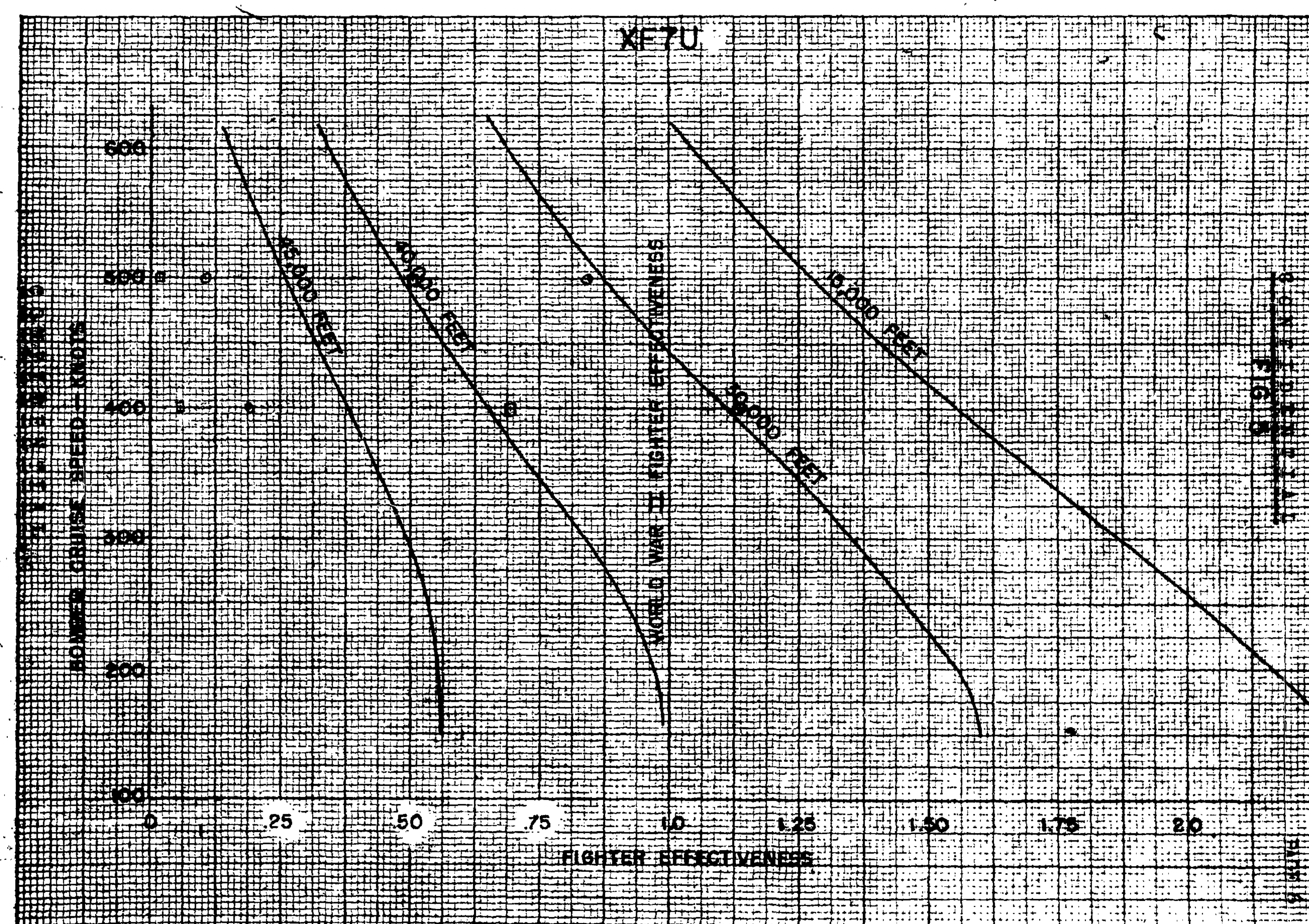
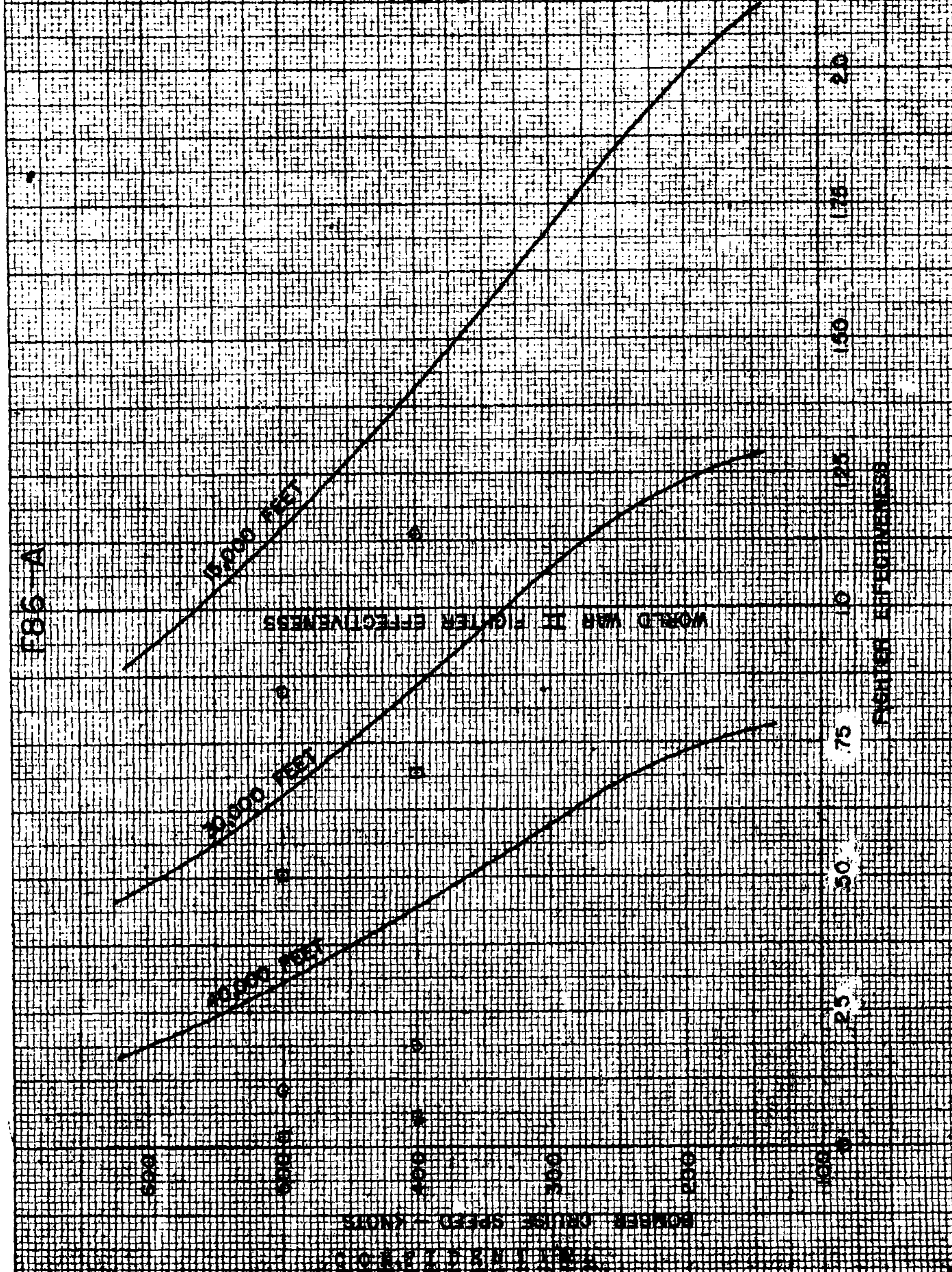

CONFIDENTIAL
FIG 5
PAGE 6
XF7U
10,000 FEET
30,000 FEET
40,000 FEET
45,000 FEET
WORLD WAR II FIGHTER EFFECTIVENESS
BOMBER CRUISE SPEED — KNOTS
600
500
400
300
200
100
0
.25
.50
.75
1.0
1.25
1.50
1.75
2.0
FIGHTER EFFECTIVENESS
CONFIDENTIAL

FIG 6


F86-A
15,000 FEET
30,000 FEET
40,000 FEET
WORLD WAR II FIGHTER EFFECTIVENESS
FIGHTER EFFECTIVENESS
0
25
50
75
100
125
150
175
200
BOMBER CRUISE SPEED — KNOTS
100
200
300
400
500
600

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INTRODUCTION

Military attack aircraft are continuously striving to improve their invulnerability to defensive type aircraft and to ground fire. Eventually, they will have to defend themselves against guided missiles too, but as yet, no effective surface-to-air or air-to-air guided missiles are known to exist. One effective means for the attack airplanes to defend themselves is to stay out of harm's reach. For this reason the emphasis in bomber design has been towards greater speed and operational altitude. Both factors contribute to the difficulties of designing and building defensive fighter aircraft, but they do not preclude defensive aircraft.

The part that higher bomber speed plays in reducing fighter effectiveness is almost self-evident but it is worth while to list the more important effects. Higher bomber speed, assuming other factors being equal,

(a) Reduces the early warning time.

(b) That in turn, requires higher rates of climb in an interceptor. In case of Airborne Patrol aircraft, time to get into position for an approach to attack is reduced, thereby requiring more accurate ground control; or better equipment to increase the search and detection range; or computing and control equipment to choose and fly the optimum approach path, or some combination of these elements.

(c) For a given distance apart at the start of a tail chase, the penetration distance of the attacking plane is larger. This comes about from the inability, for practical reasons, to maintain the same speed

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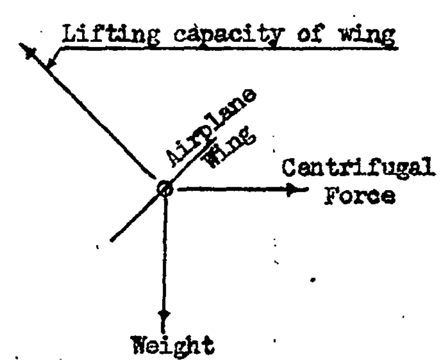
ratio between fighter and bomber as existed, for example, during World War II.

(d) In case of a frontal attack of the fighter on the bomber, higher bomber speed decreases the closing time between them for any initial distance apart. The region from which the fighter can begin an approach run to arrive sufficiently close to open fire is severely restricted. Great stress is placed upon armament and its supporting equipment. For example, a very high rate of fire is required for guns in order to achieve a given probability of a hit because of the short time available for firing. For single shot weapons the stress is placed on the directing and computing equipment. Both visual and radar detection probability is also decreased because of reduced time.

The reduction of vulnerability to fighter attack as a consequence of the bomber operating at higher altitude is less apparent to a superficial examination. Generally, the maximum altitude at which an airplane can fly is limited by either the thrust available to overcome air resistance or the lifting capacity of the wings which support the airplane. If the discussion is confined to engines which require air from outside the airplane for the operation, then the attainable altitudes for both of these limiting requirements are governed by the same natural phenomena, i.e., the decrease of air density with altitude.

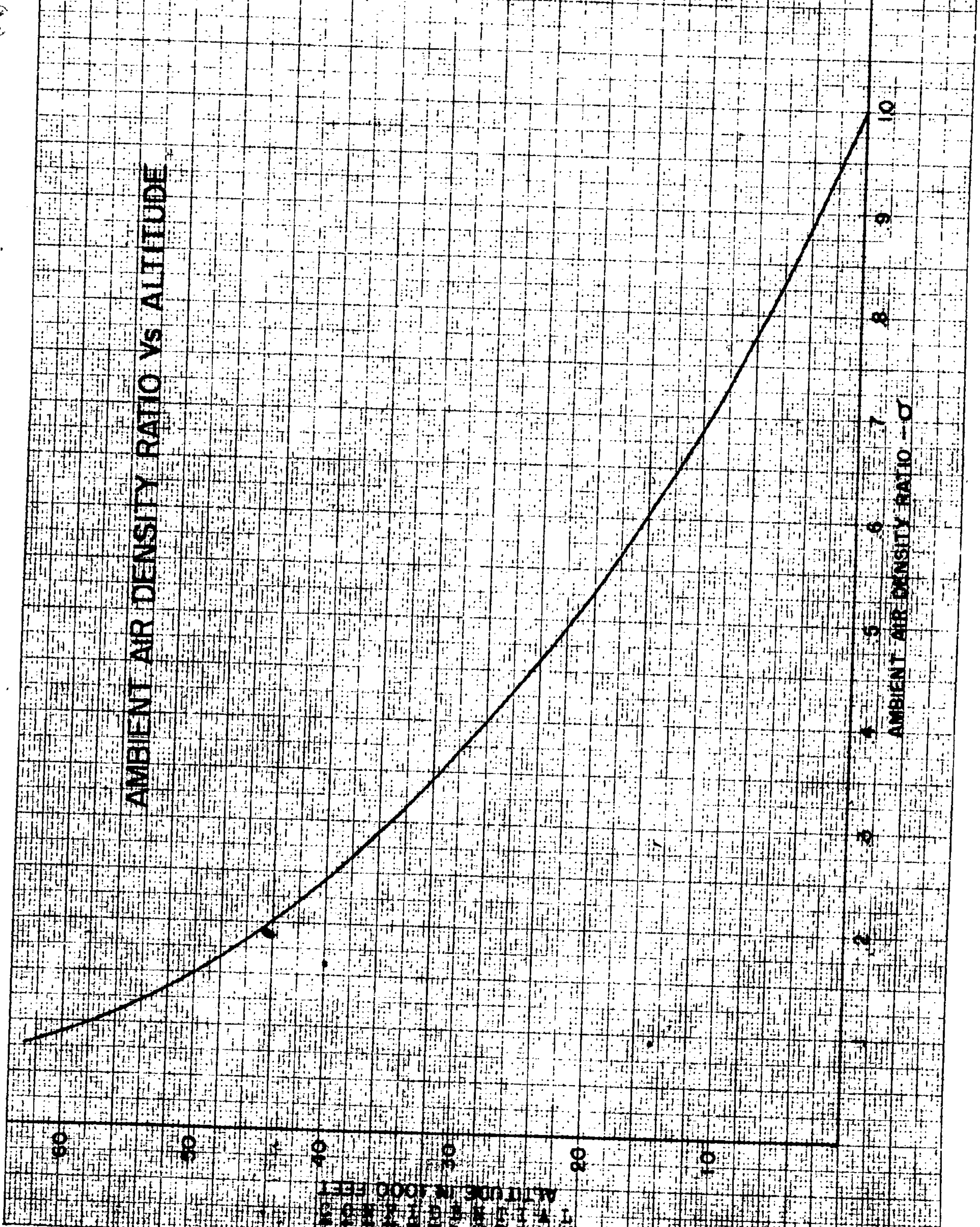
The engine, of course, establishes the absolute maximum since higher than that, enough thrust to fly would not be available even though the wings could support the airplane at some speed. Since the dimensions of a given engine are fixed and the power output of the engines, hence the thrust, depends on the quantity of air flowing through them, then it is apparent that when the density of the air is decreased the weight of air through the engine per unit time will be reduced and consequently the thrust. Figure 7 shows the variation of σ, the ratio of density of air at any altitude to the density at sea level, with altitude. Note, for example, that at 40,000 feet altitude, σ is .247; i.e., the density is only 1/4 as much as at sea level. Hence, approximately 1/4 as much thrust as at sea level would be available. The outside air temperature also decreases with altitude. This tends to increase the thrust but the effect is small compared to the air density effect.

The lifting capacity of an airplane wing is a dominant factor in the maneuverability of the aircraft. For level flight, obviously, the wing must support the weight of the aircraft; i.e., lifting capacity required equals weight of airplane. When making a horizontal turn, the airplane wing must support not only the dead weight of the airplane but must also furnish the reacting force to the centrifugal force. (See Sketch A). The resulting lifting capacity of the wing must be some number, n , times the lifting capacity required of the wing in level flight.



SKETCH A

FIG. 7


AMBIENT AIR DENSITY RATIO Vs ALTITUDE
ALTITUDE IN 1000 FEET
60
50
40
30
20
10
AMBIENT AIR DENSITY RATIO — σ
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

C O N F I D E N T I A L

The relationship between lifting capacity and other quantities is given by

$$\text{Lifting capacity} = nW = \frac{C_L \; SV^2 \sigma}{391}$$

in which

n = load factor or the lifting capacity divided by the weight.

W = weight of aircraft, lbs.

S = area of the wings, sq. ft.

and V = speed of aircraft, mph.

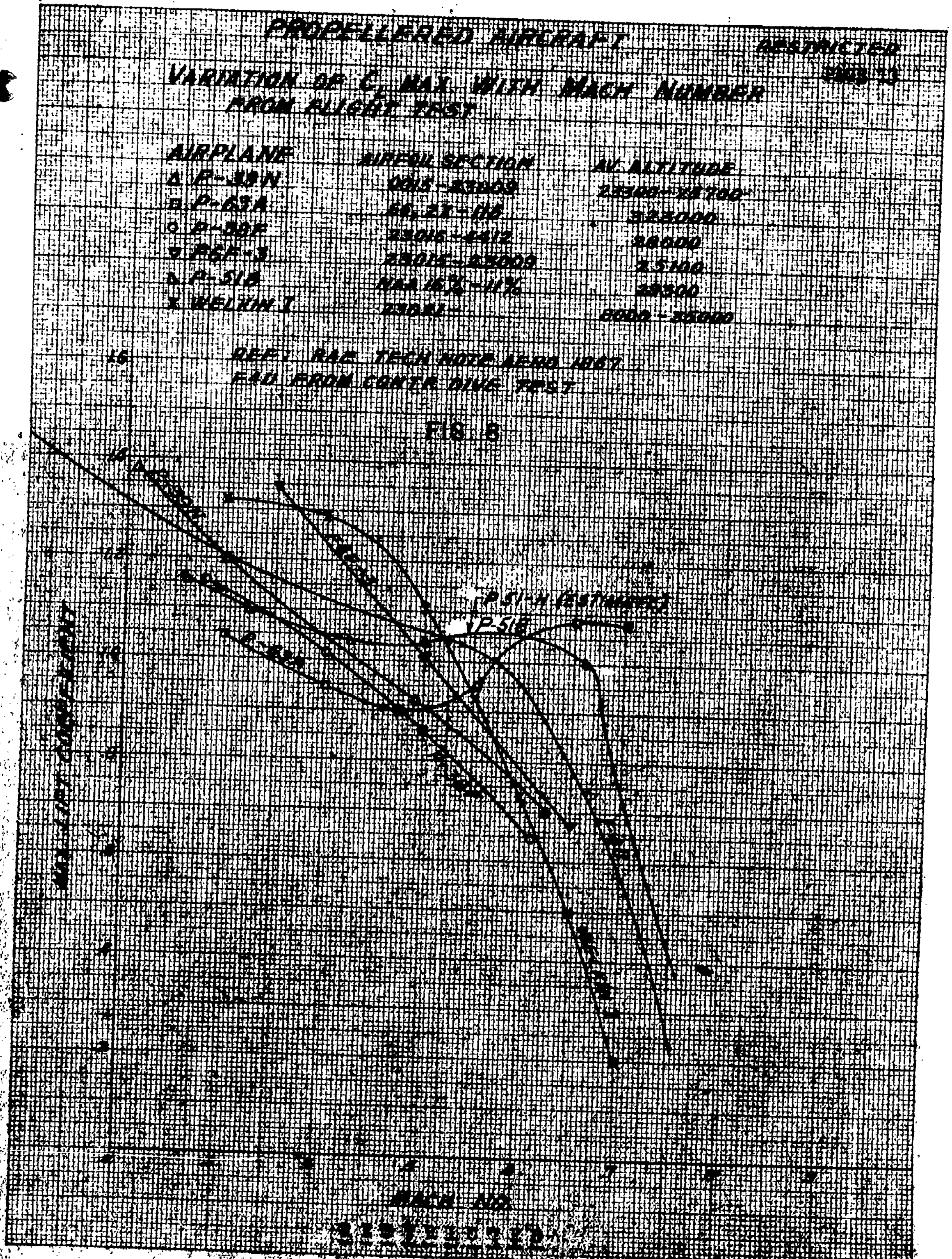
C_L = lift coefficient.

σ = ratio of ambient air density at altitude to ambient air density at sea level

It is seen that at a given altitude the lifting capacity, nW, can be increased either by increasing C_L or the speed.

Every wing has peculiar lifting characteristics which are dependent upon its geometry and speed of flight. Figures 8 and 9 show the variation of the maximum value of $C_{L_{max}}$ with speed for several airplanes. The sharp break of $C_{L_{max}}$ at a Mach number of about .6 for World War II aircraft and M ≅ .7 for postwar jet aircraft is evident. As the speed of airplanes increases beyond these speeds, the lifting capacity of the wings will be decreased because the reduction in $C_{L_{max}}$ more than offsets the increase in lift due to speed. It follows, then, that the minimum turning radius will be increased. This situation prevails up to approximately M = 1.0.

C O N F I D E N T I A L


PROPELLERED AIRCRAFT
RESTRICTED
VARIATION OF C_L MAX WITH MACH NUMBER
FROM FLIGHT TEST
AIRPLANE
AIRFOIL SECTION
AV. ALTITUDE
P-38N
0015-23009
23300-28700
P-63A
66,2X-116
22000
P-39F
23016-4412
28000
F6F-3
23015-23009
25100
P-51B
NAA 16% - 11%
29300
WELKIN I
23021-
6000-35000
REF: RAE TECH NOTE AERO 1067
FAD FROM CONTR. DIVE TEST
FIG. 8
P-51-H (ESTIMATED)
P-51B
P-63A
MAX. LIFT COEFF. C_L MAX
MACH NO.
RESTRICTED

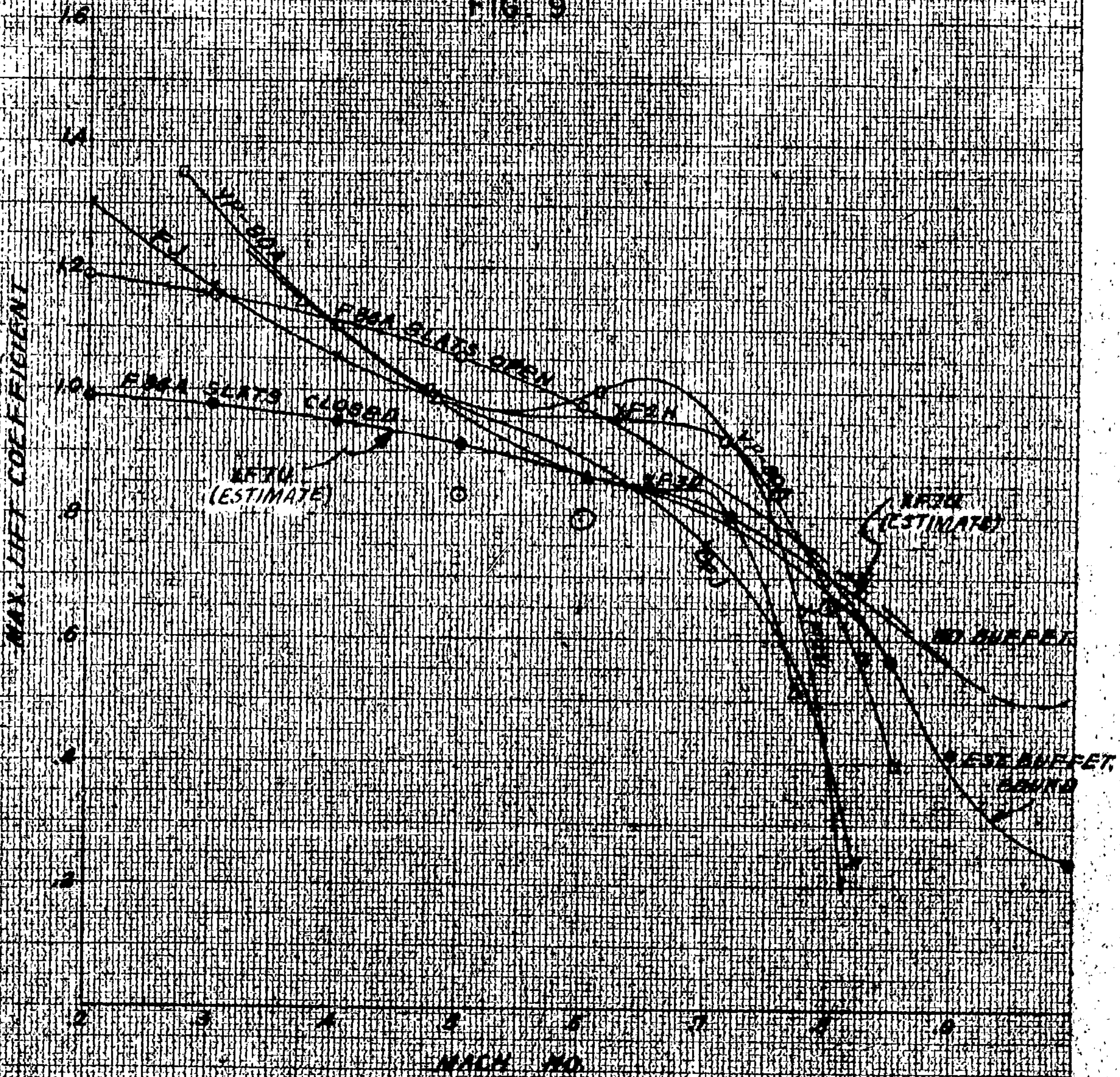
VARIATION OF C_L MAX. WITH MACH NUMBER

FROM FLIGHT TEST

AIRPLANE	AIRFOIL SECTION	AV. ALTITUDE
◻ YP-80A	65-213	20100-29600

REF: F1 RAE TECH NOTE AERO 1867
F2H FROM CONTR. DIVE DEMONSTRATION
F3D FROM CONTR. WEEKLY FLIGHT REPORT

FIG. 9



DESCRIPTION OF PROCEDURE AND DISCUSSION

In actual maneuvers, an airplane is not likely to be flown in the attitude which provides the maximum value of C_L (Figs. 8 and 9). The airplane would be at or near the stall and would require too much of the pilot's attention to fly it. Any miscue might result in uncontrolled flight. Also, most airplanes are subject to varying degrees of buffeting or shaking when flying near the stall, whether in low speed range or in high speed range and hence make poor gun platforms. Some sacrifice in maximum attainable C_L must be made in order to have good control of the aircraft and have a satisfactorily stable platform.

There is no method for establishing exact values of maximum usable C_L which will provide acceptable maneuvering flying qualities. After considering a number of relevant factors the percentages of maximum C_L shown in Table I were chosen as maximum usable values of C_L for the airplanes analyzed in this report. Using the values of $C_{L_{max}}$ in Figs. 8 and 9, together with the factors in Table I, the turning characteristics as limited by the lifting capacity of the wings of several airplanes have been computed and are shown on the overlays, Figures 12 through 21. These overlays have been enclosed in the envelope attached to the inside back cover. In order to read the actual values of radius and speed, it is necessary to superimpose the transparent overlays, with due regard to the control corners, on any one of the Figures 22 through 34.

On Figures 18 through 20, the turning radius of the XF7U as limited by available engine power are also plotted. In general, the radius of turn as limited by power will be proportionately similar for the other aircraft dis-

C O N F I D E N T I A L

TABLE I

MAXIMUM USABLE LIFT COEFFICIENTS

AIRPLANE TYPE	MACH RANGE	USABLE C_L
P51-H	0 to .675	80% $C_{L_{max}}$
	above .675	90% $C_{L_{max}}$
F4U-5	0 to .65	80% $C_{L_{max}}$
	above .65	90% $C_{L_{max}}$
XF2H	0 to .725	80% $C_{L_{max}}$
	above .725	90% $C_{L_{max}}$
YP80-A	0 to .7	80% $C_{L_{max}}$
	above .7	90% $C_{L_{max}}$
F86-A	0 to .75*	80% $C_{L_{max}}$
	above .75**	90% $C_{L_{max}}$
XF7U	complete range	85% $C_{L_{max}}$

* Slats open curve
** Buffet boundary curve

C O N F I D E N T I A L

cussed in this report.

Figures 22 through 34 are plots of the maximum constant turning radii that are permitted to an air interceptor if it is desired to approach a straight flying target without a tail chase. (Figures 35 through 38 are presentations of this same information in a more generalized form.) Other conditions imposed are that the fighter starts the turn at the particular initial distance apart, flys at constant speed, reaches a point in space a specified angle and distance off from the target and at that point has the proper heading to fire. The projectile from the fighter is required to travel 500 yards. The radii are plotted against fighter speed. In most cases two sets of curves are shown, one set being for an initial distance apart of 3 nautical miles and the other set for an initial distance apart of 6 nautical miles. For each initial distance apart several curves are plotted for different target speeds. A schematic diagram on each chart shows the initial relative headings of the two aircraft considered on that chart. Where the relative headings are such that the maximum permissible radii are large, then only the condition of 3 nautical miles initial distance apart is shown. As an approximation the radius required may be assumed to vary linearly with initial distance apart.

The radii of turn shown on Figures 22 through 34 are for mathematically exact paths and speeds.* Since such precision is not yet attainable

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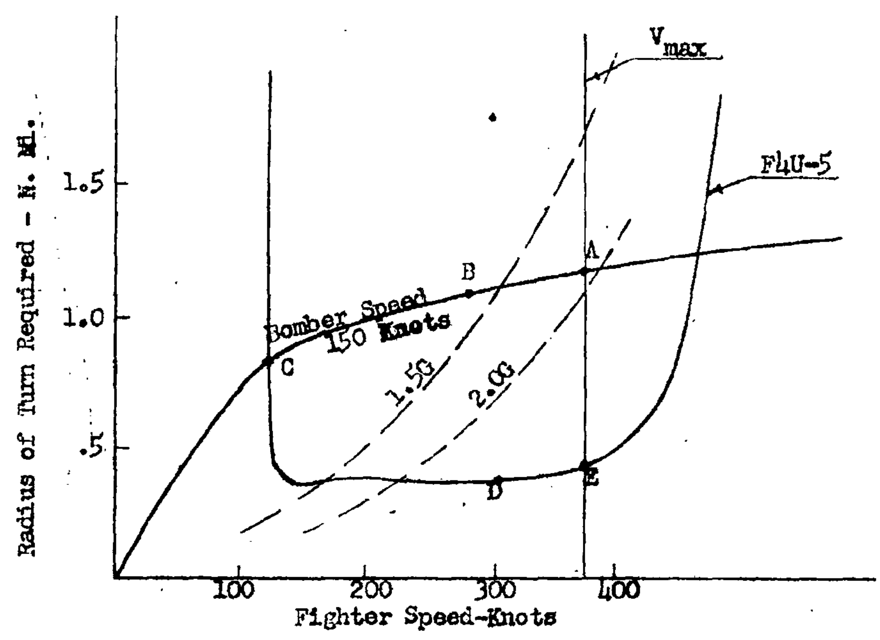
*See Appendix I for derivations of equations used to compute data for Figures 22 through 38.

C O N F I D E N T I A L

either by instruments or human judgment, a satisfactory margin of performance must be determined. By superimposing the overlays (Figures 12 through 21) on Figures 22 through 34, it can be determined whether the airplane could just make any of the specified approaches or whether it has any "margin of maneuverability."

Sketch B reproduces the result of superimposing Figure 12 on Figure 23. For the sake of clarity, only the available radius of turn of the F4U-5 (from Figure 12) and the required turn radius against a 150 knot target (from Figure 23 (extrapolated)) at an initial distance apart of 3 nautical miles are shown. The maximum level flight speed of the F4U-5 is shown by the vertical line.



SKETCH B

C O N F I D E N T I A L

Supposing now that the F4U-5 is assumed to be flying at its maximum speed at about 15,500 feet altitude. At some instant, a target appears flying in the opposite direction at 150 knots at 15,000 feet altitude. At the time of detection, the target is exactly 3 nautical miles away from the F4U-5 and at such distance to one side of it that if the F4U-5 instantaneously started a turn with the radius and speed shown by point A on Sketch B it would reach a point in space from which it could fire instantaneously with the proper lead. The distance traveled by the projectile would be 500 yards. It will be noted that at the conditions of point A the F4U-5 must pull about 1.8Gs. The height advantage of 500 feet is estimated,by calculation,to give him the necessary additional force (gravity component) to maintain his speed and radius of turn at the constant values specified by point A. The path flown is shown on Figure 10 and marked A.

If the pilot should prefer to make the tightest turn that is possible, then he could bank and pitch the F4U-5 to such an attitude that it would have the speed and radius combination of point E of Sketch B. He could not, however, from an initial altitude of 15,500 feet, maintain the speed at point E and would slow down to some speed that might be indicated by point D on the sketch, depending on the angle through which he turned and the power needed to maintain a steady turn. In the case of the F4U-5, it is estimated that to turn through 160° would slow the aircraft down from 372 knots to 320 knots. No altitude need be lost. The airplane would successively assume the radii and speed combinations between points E and D. The path prescribed by this maneuver in approaching the target is shown on Figure 10 and marked E. It is possible to slow down even further without losing altitude, say to point D, but the radius of turn is now becoming larger.

It becomes apparent now that the airplane could assume any combination of speed and radius of turn that is contained in the area A B C D E. Of course, the airplane could also fly any combination of speed and radius above line A B C but that would violate the initial conditions of the problem as shown in the diagram of Figure 23, allowing greater penetration of the target for any given speed. On the other hand only the combinations of speed and radii of line A B C are needed to just meet the geometry of the diagram. With each combination of speed and radius on line A B C there are only two points (one on each side of the target flight path) on the 3 nautical mile detection perimeter where the fighter must be in order to fly the prescribed path. If a fighter airplane available radius of turn lies below line A B C, then it can be translated as having the ability to reach the point of fire from an arc, rather than just one point, of the 3 nautical mile perimeter as is indicated in Figure 10, or the ability to vary the path from a given point, for example, path V of the same figure; therefore, the size of the region (area A B C D E of Sketch A) between the available radius of turn of a fighter and the required radius of a given kinematic problem is a measure of the "excess maneuverability" that the fighter has. He can employ the "excess maneuverability" to make corrections for initial positioning or orientation errors or errors in judgment of direction and speed of target after he has begun the approach.

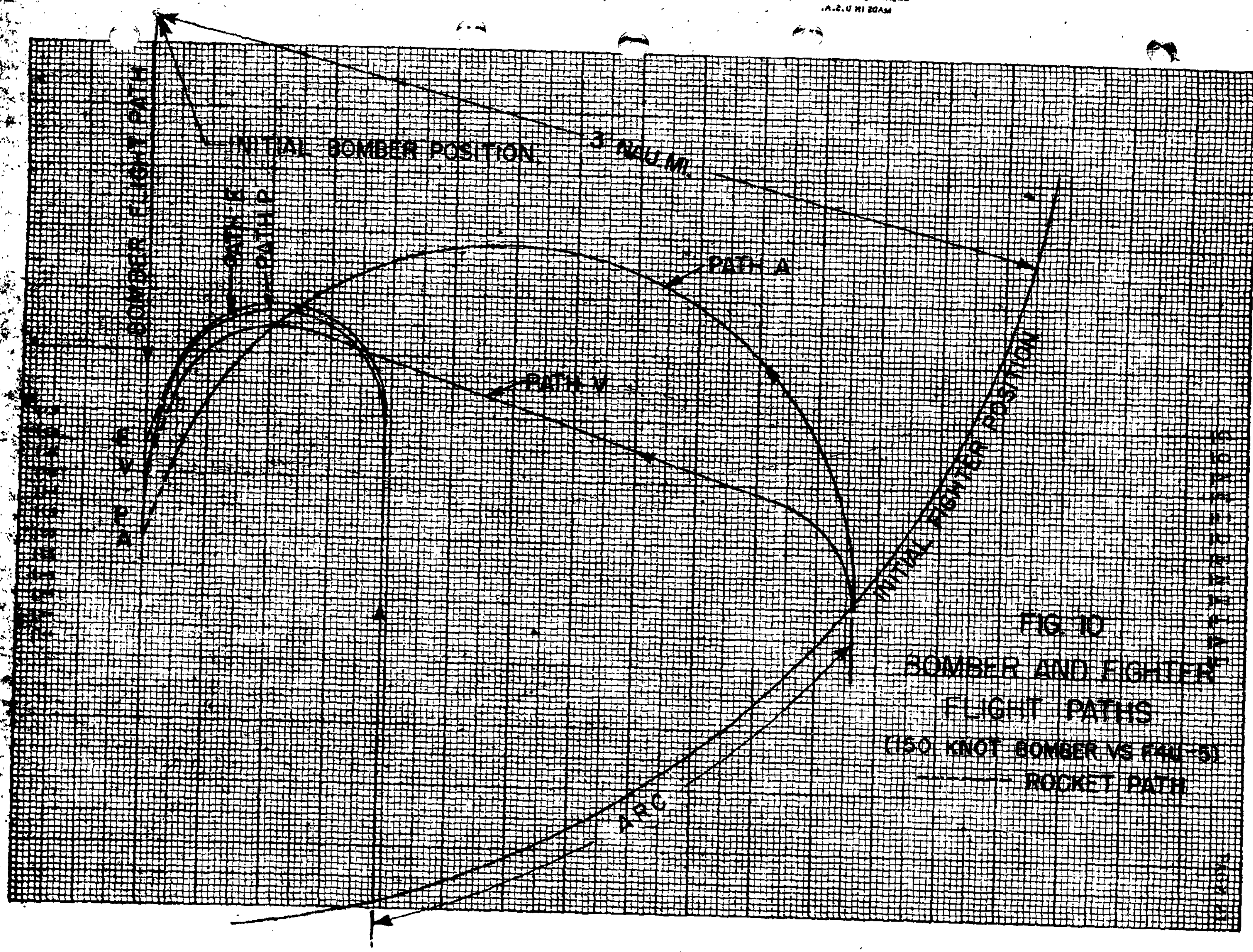


FIG. 1D
BOMBER AND FIGHTER
FLIGHT PATHS
(150 KNOT BOMBER VS F4U-5)
------- ROCKET PATH

C O N F I D E N T I A L

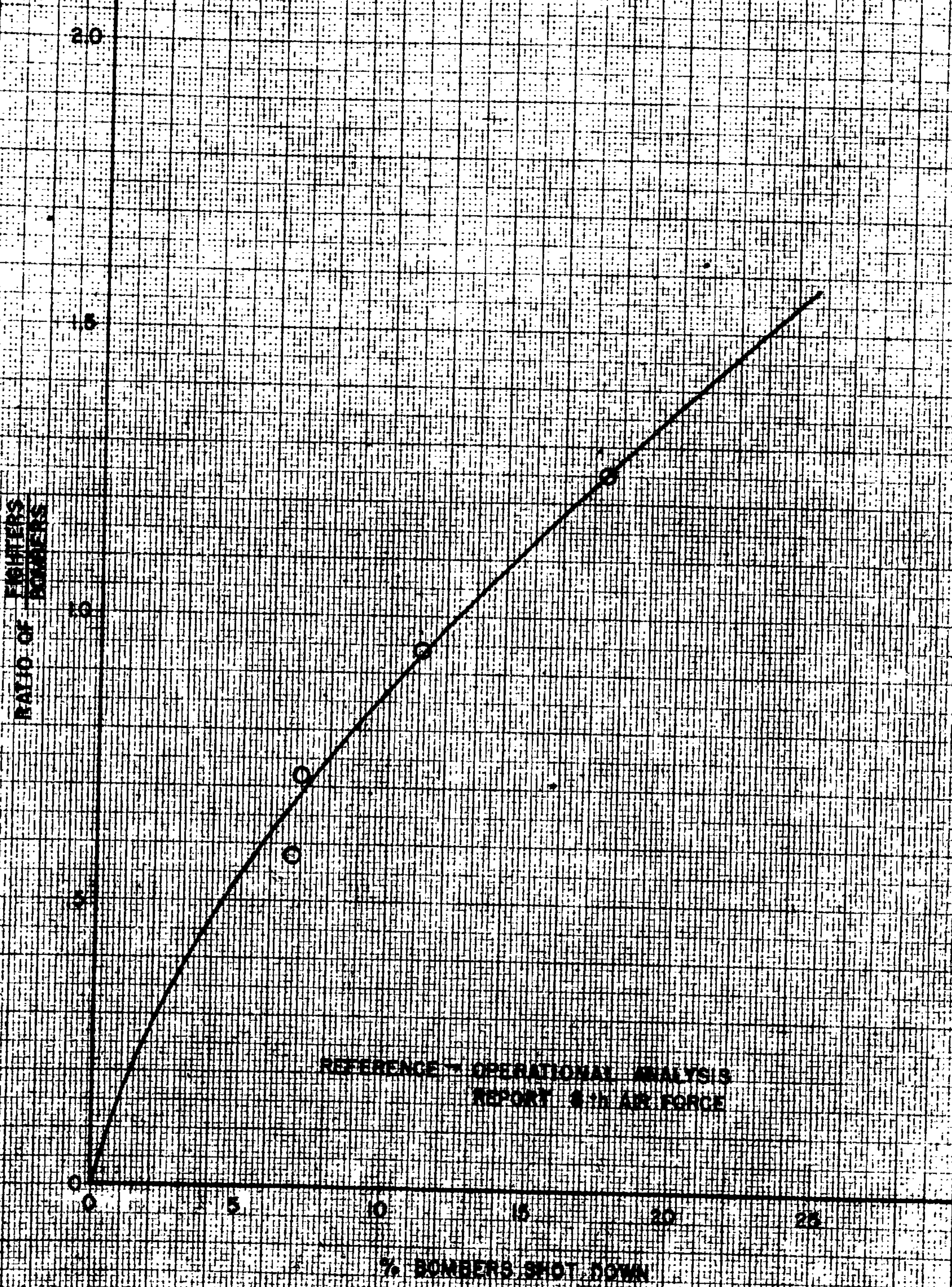
The question now arises, "Just how much excess maneuverability provides a satisfactory margin?"

Enemy aircraft in World War II, when attacking our unescorted bombers in large numbers, were highly successful. For example, in the Schweinfurt raid of 14 October 1943, about 230 bombers took part. Opposition fighter aircraft participating in combat were about 290, or a ratio of 1.25 fighters to one bomber. Bomber losses in that raid were 26% or 60 aircraft of which 1/3 or 20 may be assumed due to flak or other causes and the remainder 40 or 17.4% of attacking bombers due to enemy aircraft. Again, on January 11, 1944, 555 bombers took part in an attack and were opposed by 400 enemy fighters. A total of 60 bombers were lost, presumably about 40 due to enemy fighters. Here, the ratio of fighters to bombers was .72 and the bomber losses 7%. Figure 11 is a plot of the data on only 4 missions and is included for general interest only.

The fighters were not all committed at one time against the total number of bombers. The Germans developed tactics of concentrating as many as 5 or more fighter aircraft attacking from a number of directions against a single bomber. It may be argued then, that German fighters had the capability of approaching within firing range of the bombers from several directions. Therefore, an examination of the margin of "excess maneuverability" of the German fighters against the B17s would give an "effectiveness measure" which would be related to World War II bomber losses. By means of the overlays and charts the excess maneuverability or effectiveness of present day fighters against varying speed targets can be determined and compared with the effec-

C O N F I D E N T I A L

FIG. 11


2.0
1.5
1.0
.5
0
RATIO OF $\frac{FIGHTERS}{BOMBERS}$
0
5
10
15
20
25
% BOMBERS SHOT DOWN
REFERENCE — OPERATIONAL ANALYSIS
REPORT 8th AIR FORCE

C O N F I D E N T I A L

tiveness of German fighters against U. S. Bombers of World War II. Assuming that all other factors between fighters and bombers (armament, fire control, crew competence, etc.) are relatively the same as they were in World War II, then the losses would be proportional to the effectiveness measures.

For the determination of the World War II effectiveness measure, the German fighter, the FW190, was considered to be representative. The U. S. B17G cruising at 200 knots at 23,000 feet was used as a representative target.

Sufficient information on the FW190 was not available to make a detailed analysis. However, from a performance standpoint, the F4U-5 is sufficiently similar to the FW190 to permit the use of its applicable characteristics to compute the effectiveness base. A comparison of some of the more applicable performance characteristics of the FW190 and F4U-5 are shown below:

	FW190	F4U-5
Combat Wing Loading	46.7 lbs/sq ft	41.5 lbs/sq ft
Combat Speed @ 15000'	372 kts	370 kts
Combat Speed @ 31000'	395 kts	398 kts
Service Ceiling	44000'	43000'

Except for wing loading, which is an important parameter, the performance characteristics are quite similar. Accordingly, the F4U-5 was used to represent German fighter capability.

The next problem which arises is to determine which of the Figures 32 through 34 need be used and what weight to assign to each.

C O N F I D E N T I A L

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From an Operations Analysis Report of the Eight Air Force (C5-5521, AF), the following data on direction of attack was obtained:

TABLE II

Direction of Attack	Period Jul. Aug. Sept. 1943	Period Jan. Feb. Mar. 1944	Period Apr. May 1944	Average of all Periods
	Per Cent of Total Attacks			
From Nose (11, 12 & 1 o'clock)	26.7	30.1	44.6	32.5
From Beam (2, 3, 4 & 8, 9, 10 o'clock)	31	27.6	22.6	27.6
From Tail (5, 6 & 7 o'clock)	42.3	42.3	32.8	39.9

In this analysis, to represent nose attacks the average of the effectiveness values of Figures 32 and 34 were used; for beam attacks the average of effectiveness values of Figures 29 and 31 were used; and for tail attacks the effectiveness value of Figure 25 was used. Each of the average values is then multiplied by the proper average percentage that attacks occurred from that direction as shown in Table II. Adding the resultant values from the three directions gives the effectiveness number.

The discussion to this point has assumed a single shot type weapon which is fired on a collision path at 500 yards from the target, for example, a salvo of 2 3/4 inch rockets. It is possible, however, to fly a minimum radius turn (radii and speed combinations along line E D C of Sketch B) which becomes tangent to a pursuit path at the maximum acceleration point of the pursuit

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path and to follow the path from that point into the target. This situation holds provided the ratio of speed of fighter to bomber is less than 2*. Path P of Figure 10 illustrates the resulting flight path.

In order to give an indication of how close to a target a fighter can approach, follow a pursuit path from there in and yet not exceed some maximum permissible acceleration, Figures 39 through 43 have been prepared**. They show the combinations of Gs, distances and angles off the stern at which they occur for various bomber fighter speed combinations. For example, let a fighter speed be 475 knots and a bomber speed be 250 knots. The speed ratio,

$$\mathcal{E} = \frac{475}{250} = 1.9.$$

The value of fighter speed, v, times bomber speed, V, is

$$vV = 475 \times 250 = .119 \times 10^6.$$

Now suppose that a given fighter may not exceed 2G, then entering Figure 43 at 2G and moving across to $vV = .119 \times 10^6$ the maximum distance, r_c, from which a pursuit path may be followed is 600 yards. The maximum allowable angle off, α_c, is:

$$\alpha_c = \cos^{-1}\frac{\mathcal{E}}{2} = \cos^{-1}.95 = 18.2^\circ$$

While Figures 39 through 43 do not contain information directly applicable

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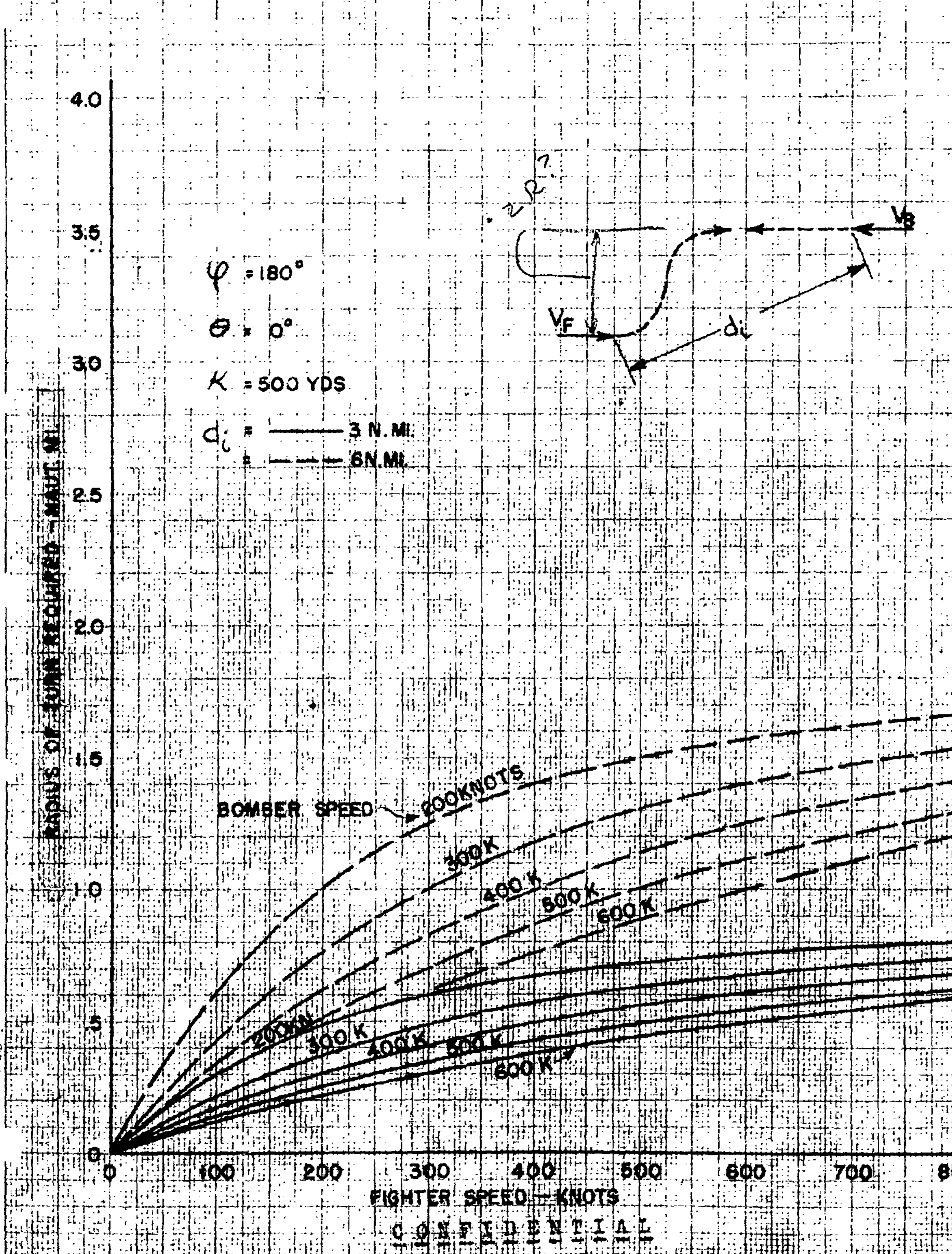
* For speed ratios equal to or greater than 2, maximum acceleration is not obtained until the point of interception is reached.

** See Appendix II for equations used in preparation of these figures.

to other than the critical azimuth angles, they may be useful in other cases as well. For an aircraft beginning a non-lead pursuit path at any given speed ratio, ε , range, r, and azimuth angle, α , it may be stated that (1) if α is less than α_c, then the acceleration required during the remainder of the pursuit path will be less than that read from the graphs at $r_c = r$ and (2) if α is greater than α_c, then the acceleration required at some point (or points) will exceed that read from the graphs at $r_c = r$.

FIG. 22



φ = 180°
θ = 0°
K = 500 YDS
d_i = 3 N. MI.
= 6 N. MI.
V_B
V_F
d_i
BOMBER SPEED 200 KNOTS
300 K
400 K
500 K
600 K
200 KN
300 K
400 K
500 K
600 K
RADIUS OF TURN REQUIRED — NAUT. MI.
FIGHTER SPEED — KNOTS
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
100
200
300
400
500
600
700
800

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FIG. 23

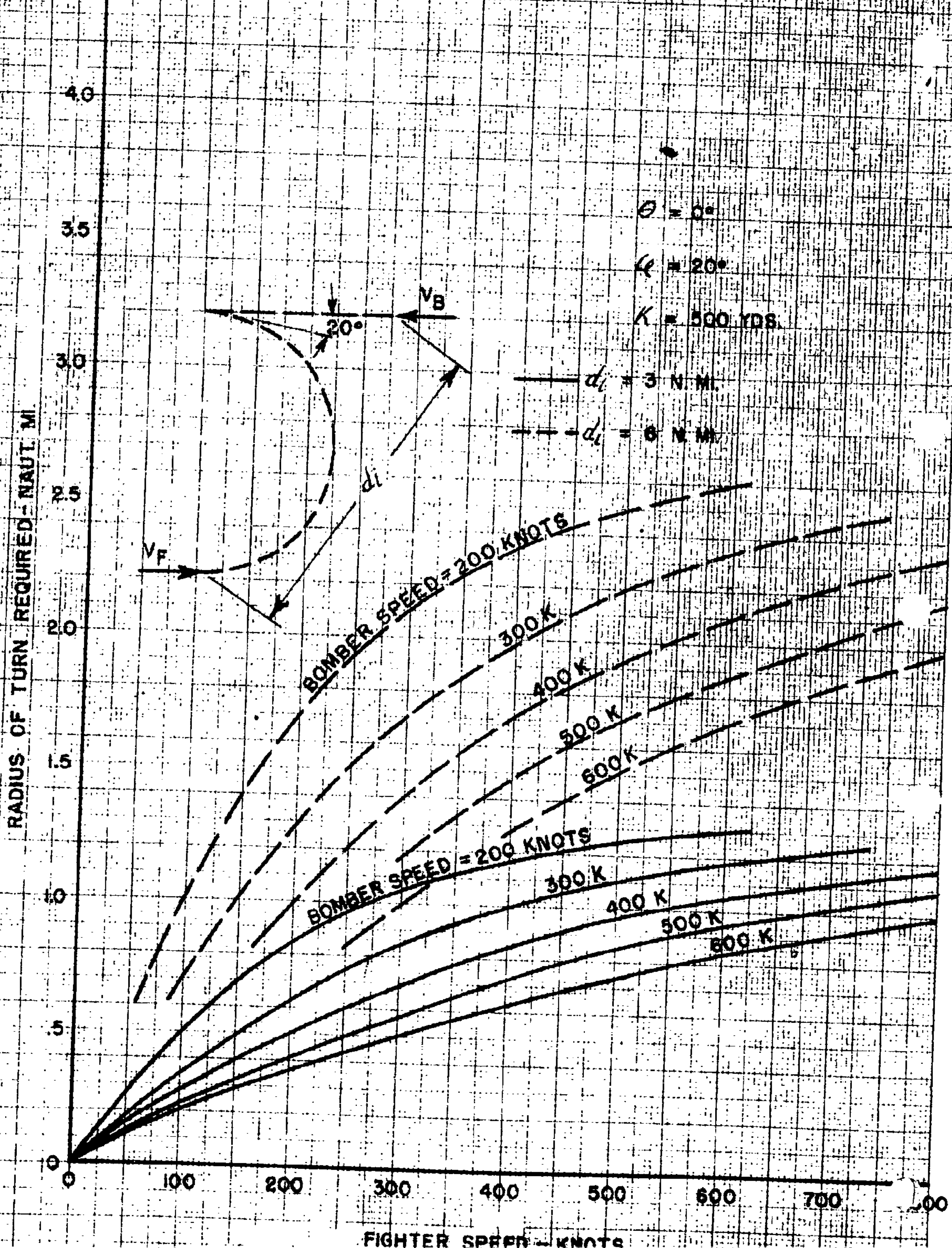

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FIG. 24

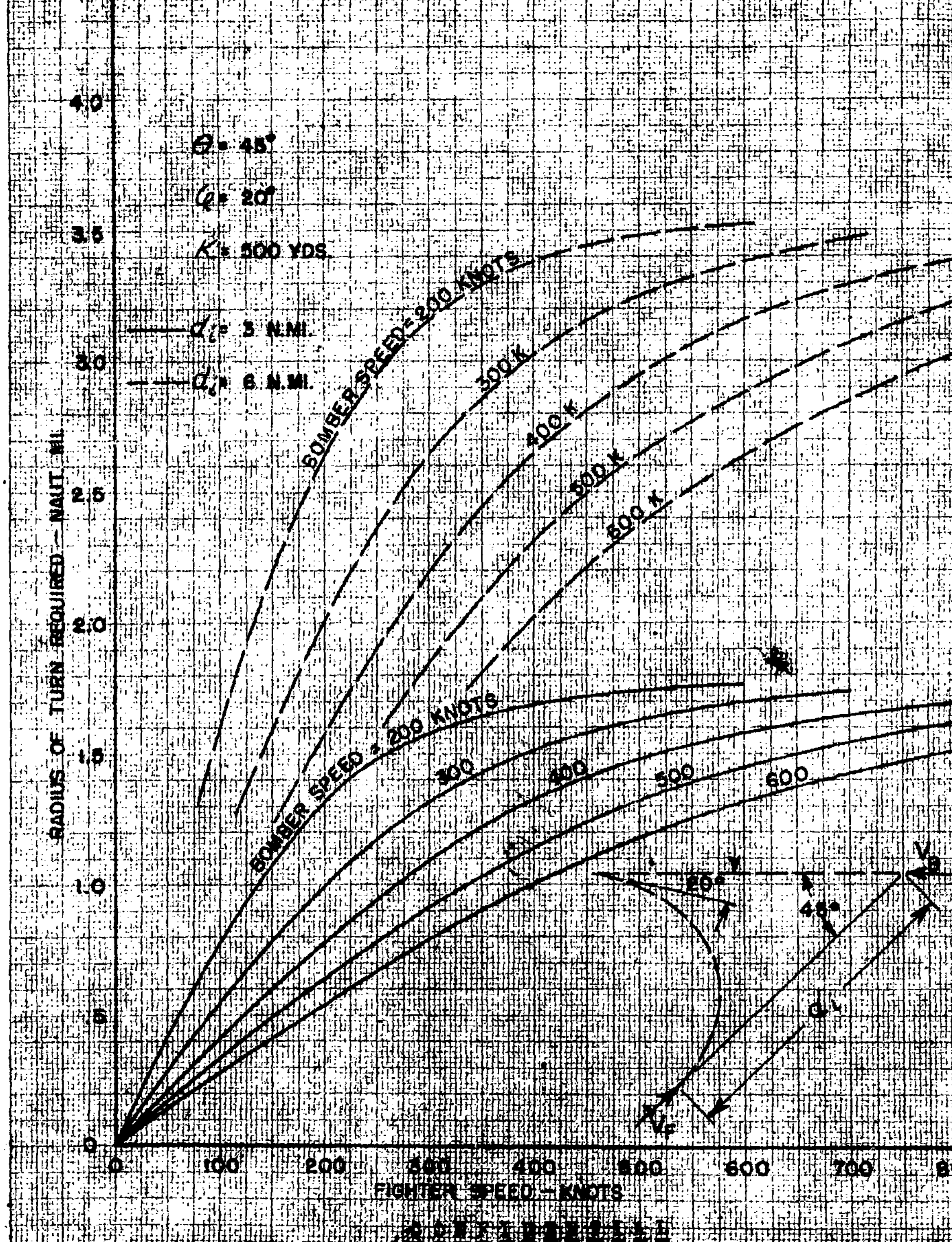

θ = 45°
Q = 20°
K = 500 YDS.
d = 3 N.MI.
d = 6 N.MI.
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
BOMBER SPEED = 200 KNOTS
300
400
500
600
20°
45°
V
VB
VF
d
RADIUS OF TURN REQUIRED — NAUT. MI.
FIGHTER SPEED — KNOTS
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
100
200
300
400
500
600
700
800

FIG. 25

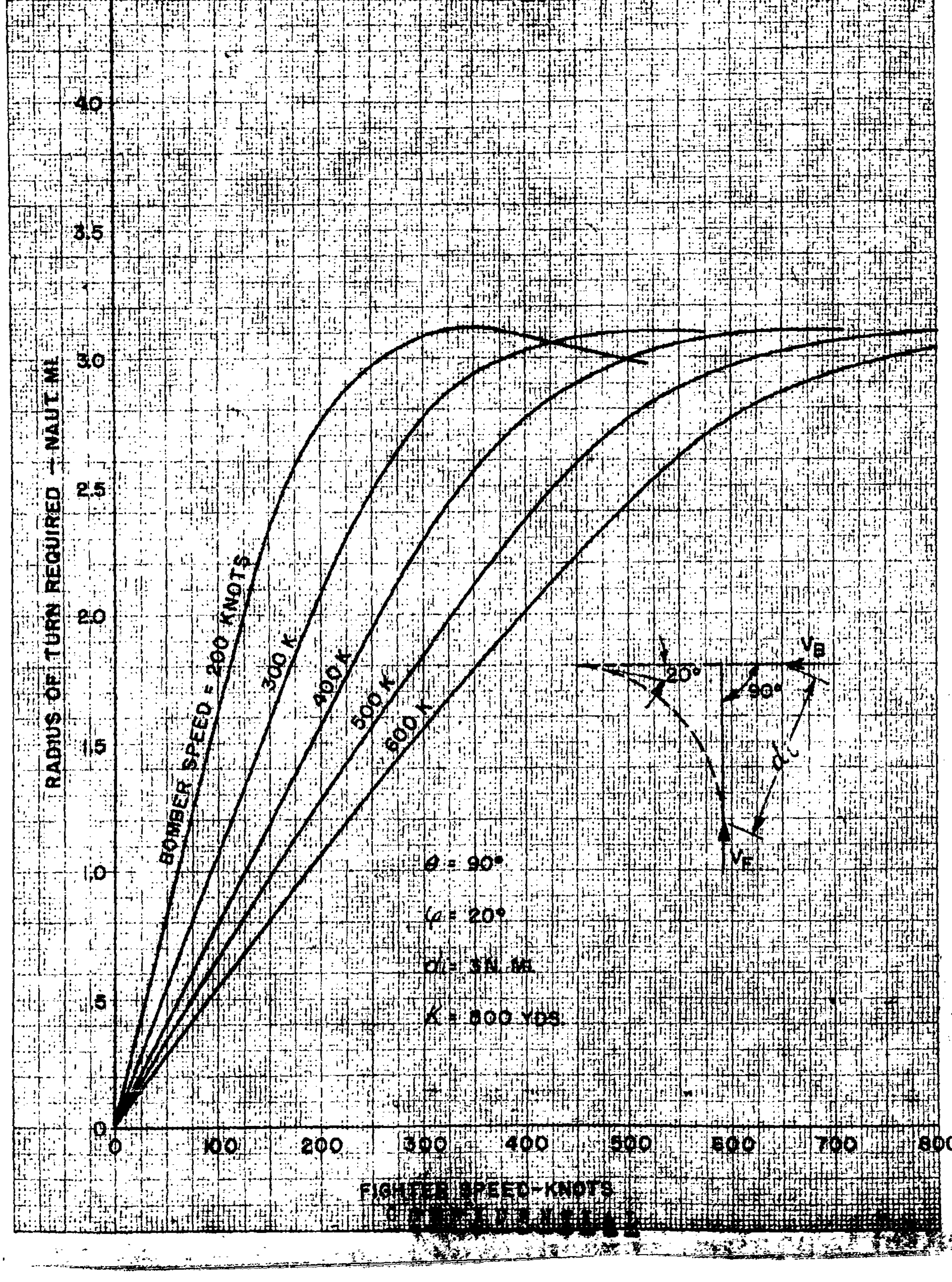
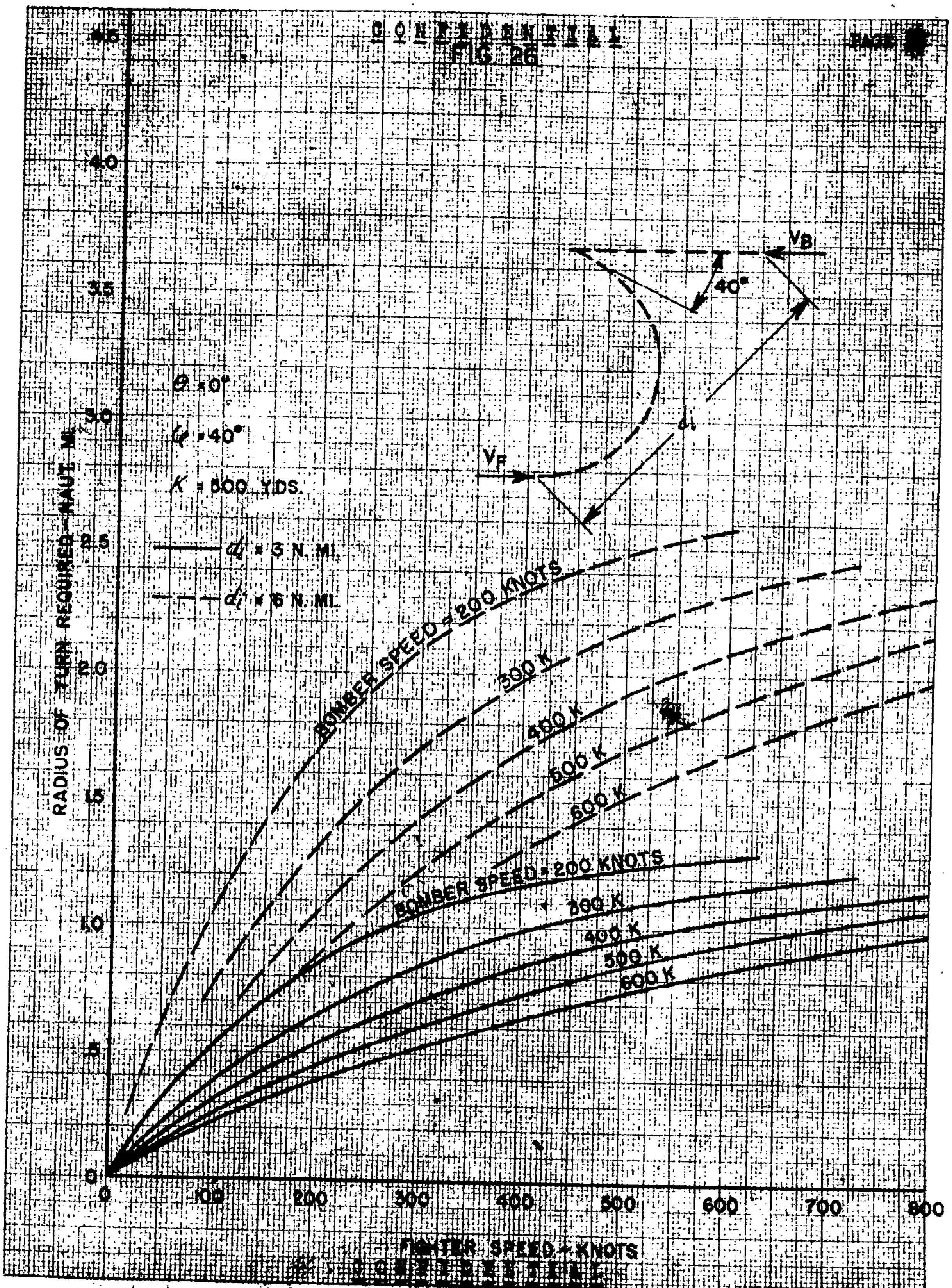
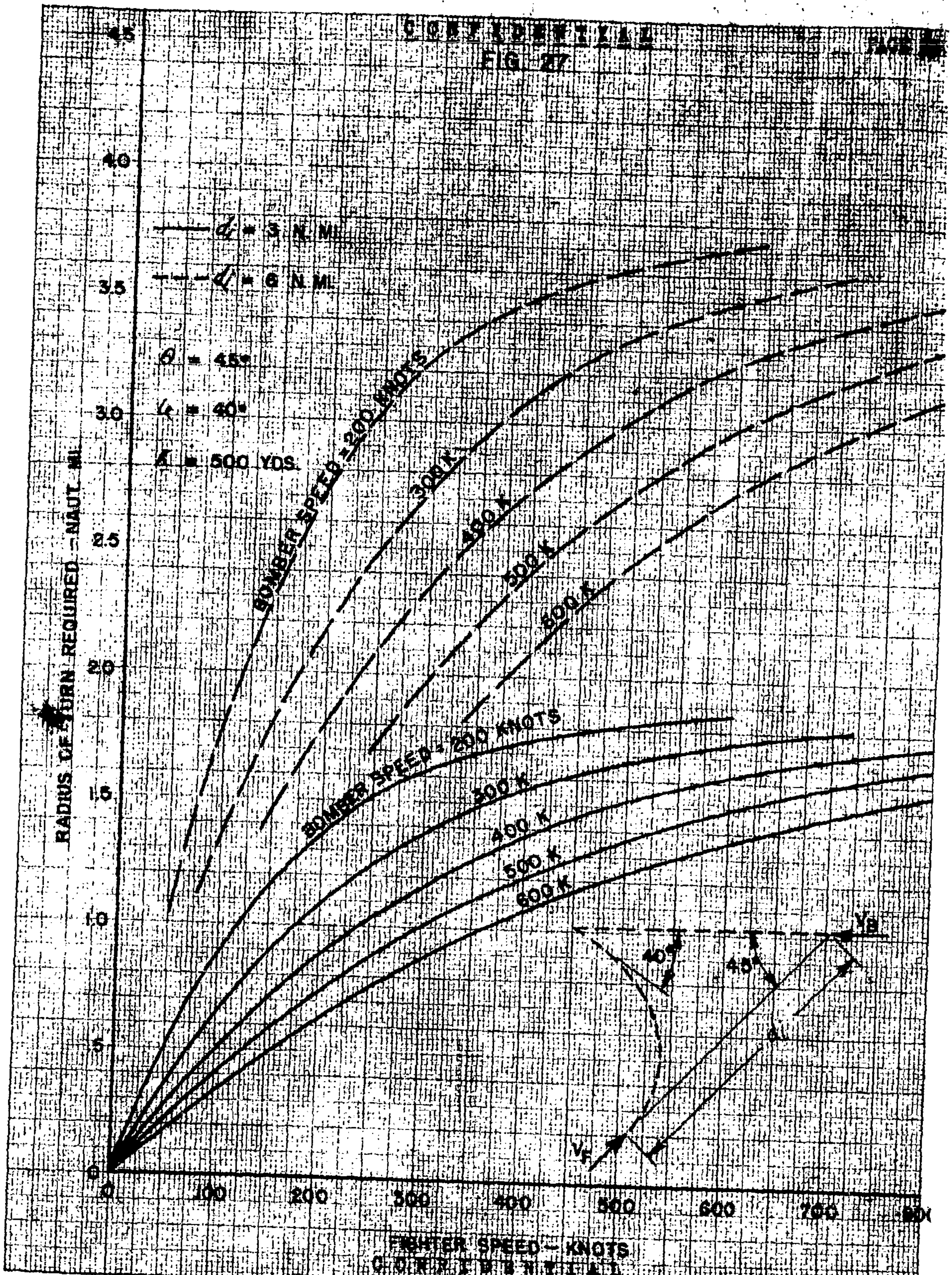

RADIUS OF TURN REQUIRED — NAUT. MI.
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0
100
200
300
400
500
600
700
800
FIGHTER SPEED-KNOTS
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
θ = 90°
φ = 20°
d = 3 N. MI.
K = 800 YDS.
20°
90°
V_B
V_F
d

FIG 26



RADIUS OF TURN REQUIRED - NAUT. MI.
FIGHTER SPEED - KNOTS
θ = 0°
ψ = 40°
K = 500 YDS.
d_i = 3 N. MI.
d_i = 6 N. MI.
V_B
V_F
40°
d_i
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
100
200
300
400
500
600
700
800

FIG. 27



— d = 3 N. MI.
– – d = 6 N. MI.
θ = 45°
ψ = 40°
R = 500 YDS.
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
40°
45°
d
V_B
V_F
RADIUS OF TURN REQUIRED — NAUT. MI.
FIGHTER SPEED — KNOTS
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0
100
200
300
400
500
600
700

FIG. 28

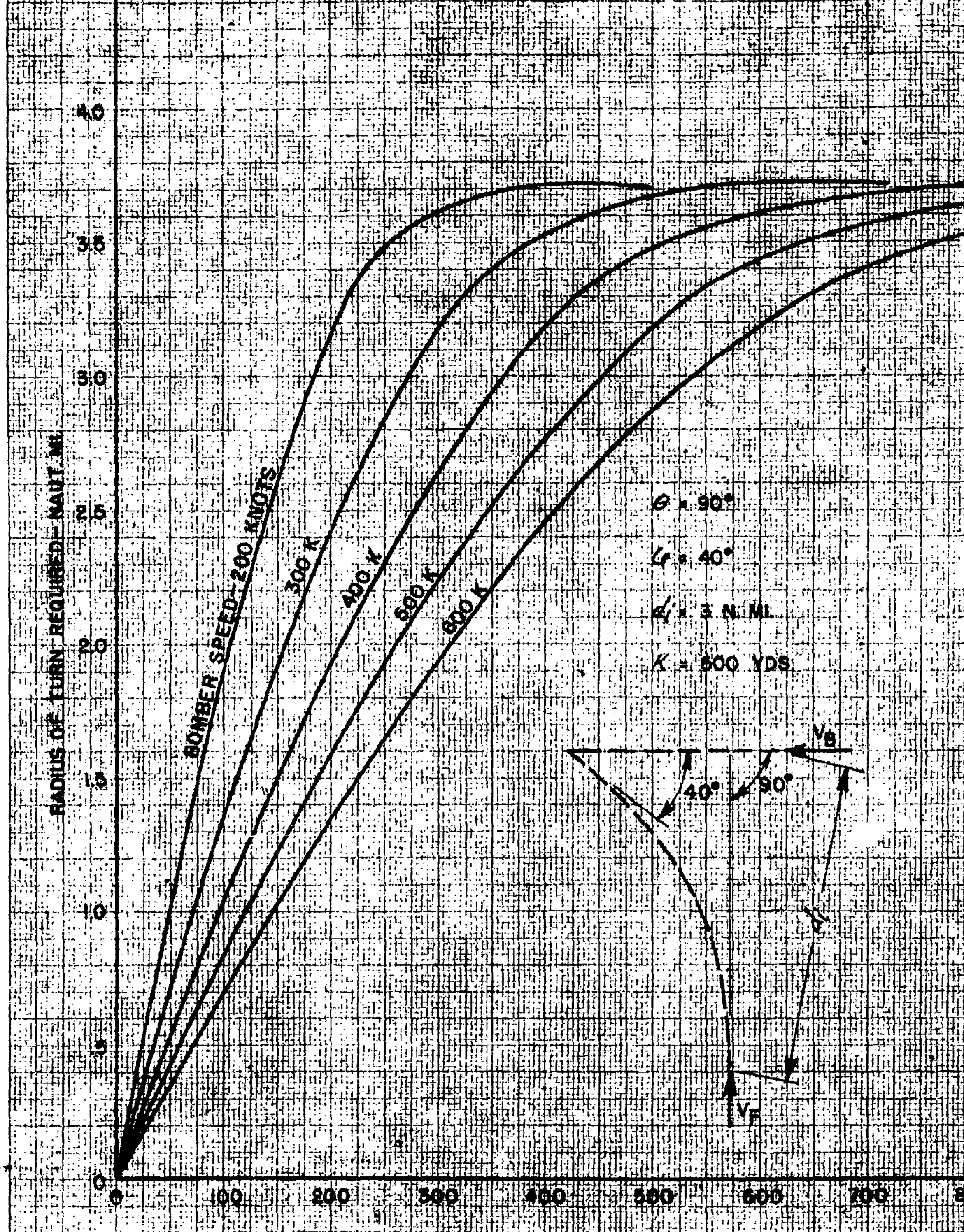

RADIUS OF TURN REQUIRED - NAUT. MI.
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
100
200
300
400
500
600
700
800
BOMBER SPEED - 200 KNOTS
300 K
400 K
500 K
600 K
θ = 90°
ψ = 40°
d = 3 N. MI.
K = 600 YDS.
V_B
40°
90°
d
V_F
FIGHTER SPEED - KNOTS

FIG. 29

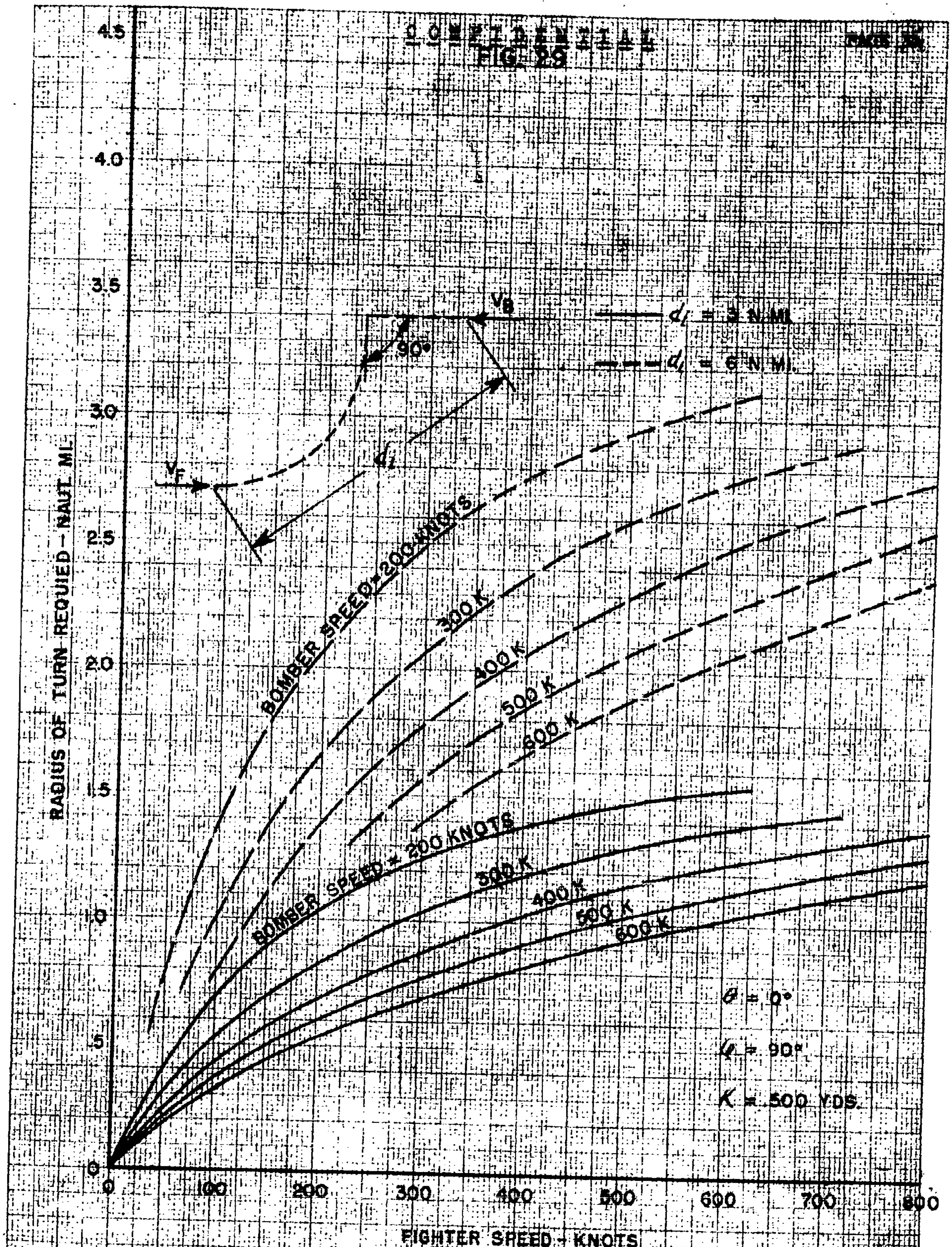

4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
RADIUS OF TURN REQUIED - NAUT. MI.
V_B
V_F
90°
d_i
d_i = 3 N. MI.
d_i = 6 N. MI.
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
θ = 0°
ψ = 90°
K = 500 YDS.
0
100
200
300
400
500
600
700
800
FIGHTER SPEED - KNOTS

FIG. 30

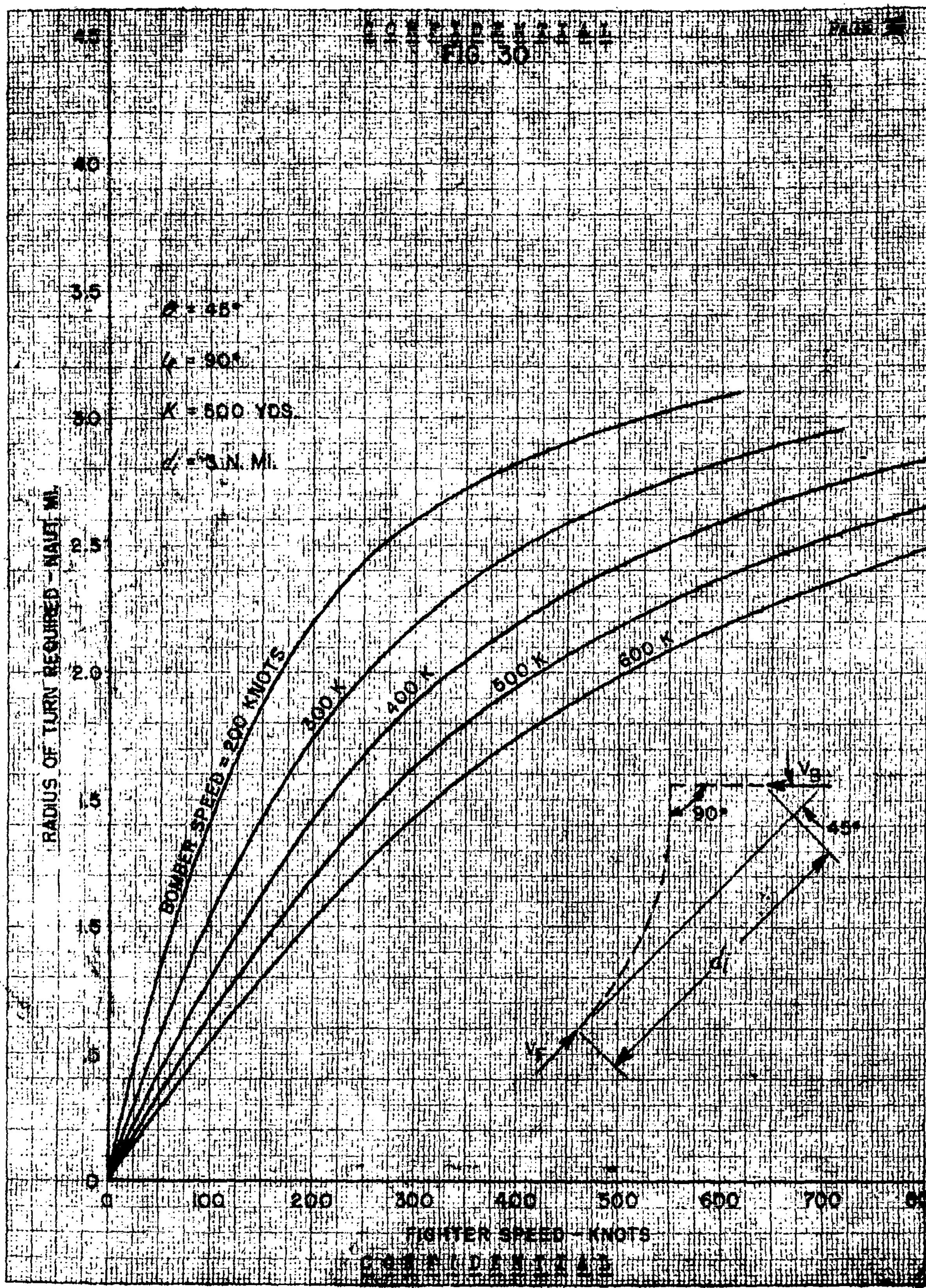

θ = 45°
ψ = 90°
K = 500 YDS.
d_i = 3 N. MI.
RADIUS OF TURN REQUIRED - NAUT. MI.
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
V_B
90°
45°
d_i
V_F
0
100
200
300
400
500
600
700
800
FIGHTER SPEED - KNOTS

FIG. 31

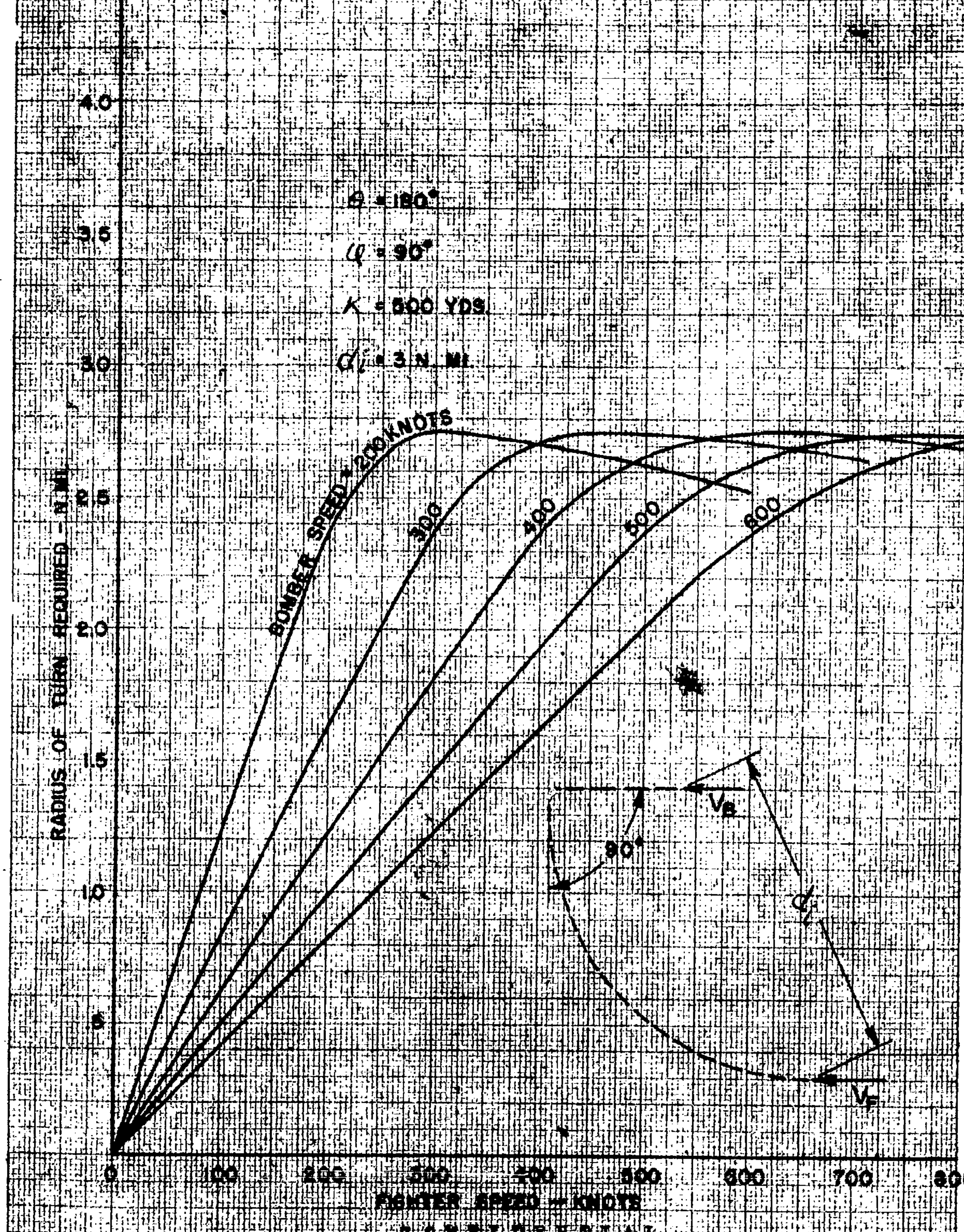
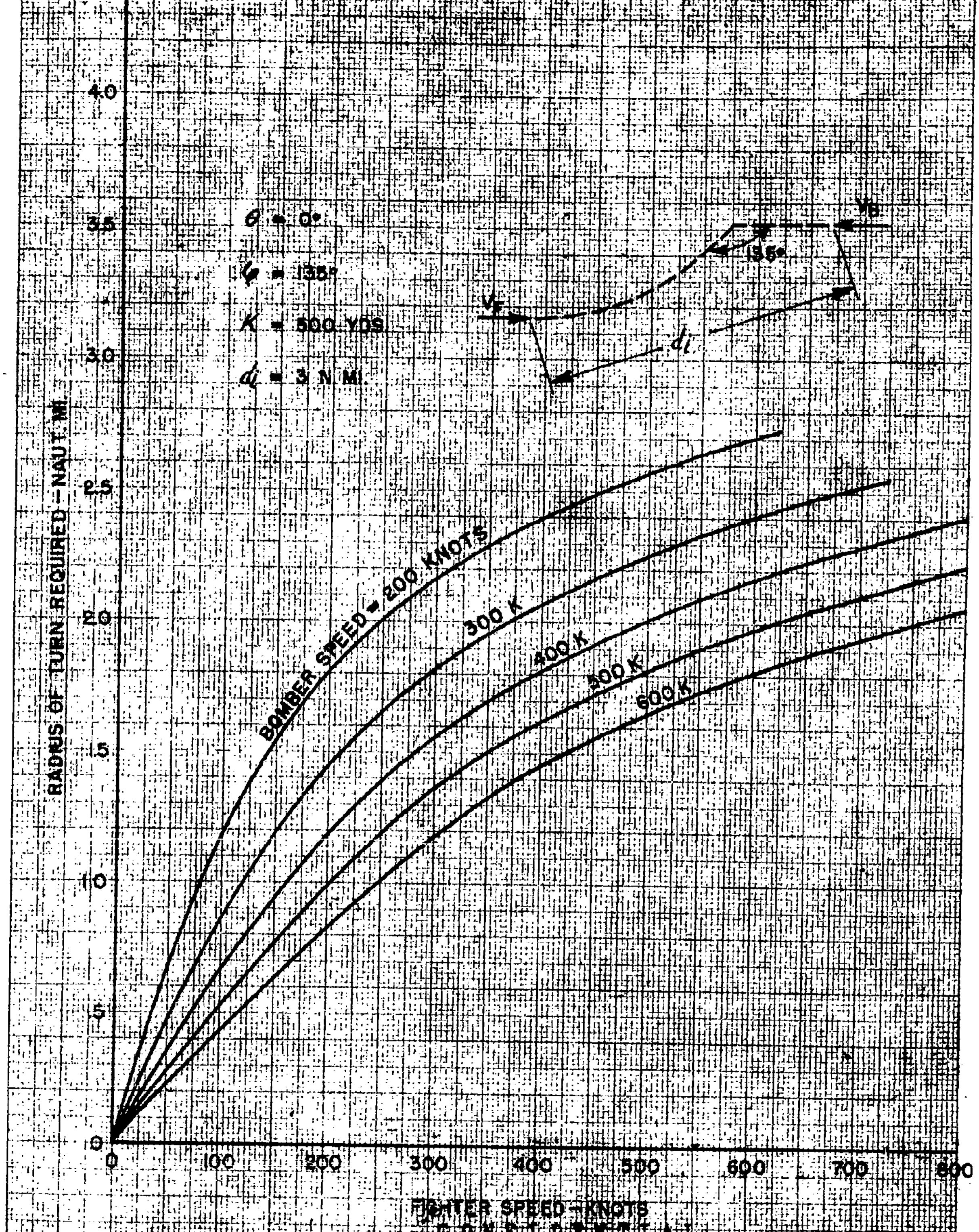

θ = 180°
φ = 90°
K = 500 YDS.
d_i = 3 N. MI.
BOMBER SPEED = 200 KNOTS
300
400
500
600
90°
V_B
d_i
V_F
RADIUS OF TURN REQUIRED – N. MI.
FIGHTER SPEED – KNOTS
0
100
200
300
400
500
600
700
800
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

FIG. 32



$\theta = 0°$
$\varphi = 135°$
$K = 500$ YDS
$d_i = 3$ N MI
V_F
V_B
135°
d_i
RADIUS OF TURN REQUIRED—NAUT MI
FIGHTER SPEED—KNOTS
BOMBER SPEED = 200 KNOTS
300 K
400 K
500 K
600 K
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
100
200
300
400
500
600
700
800

FIG. 33

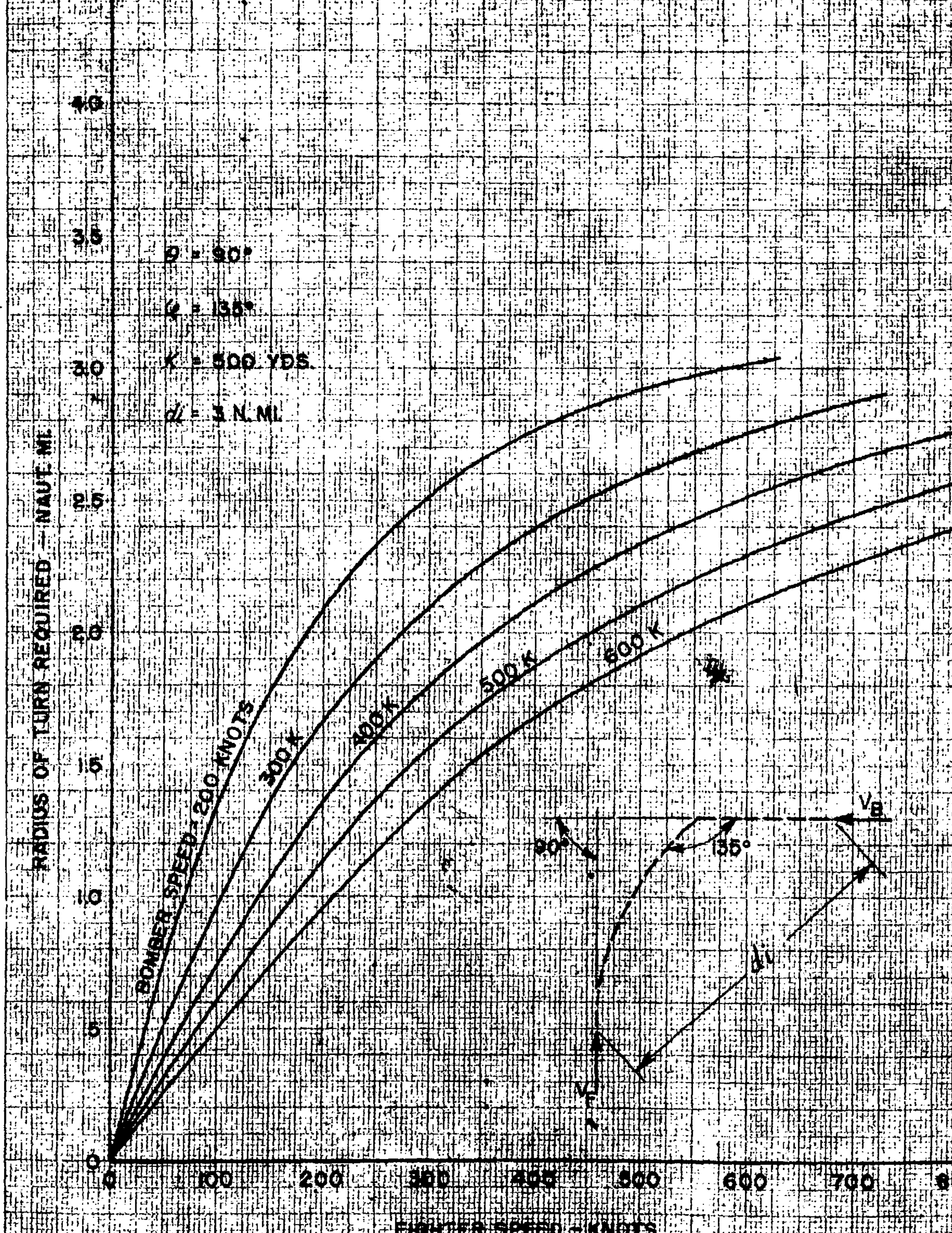

RADIUS OF TURN REQUIRED — NAUT. MI.
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
θ = 90°
φ = 135°
K = 500 YDS.
d = 3 N. MI.
BOMBER SPEED - 200 KNOTS
300 K
400 K
500 K
600 K
V_B
90°
135°
d
V_F
0
100
200
300
400
500
600
700
800
FIGHTER SPEED - KNOTS

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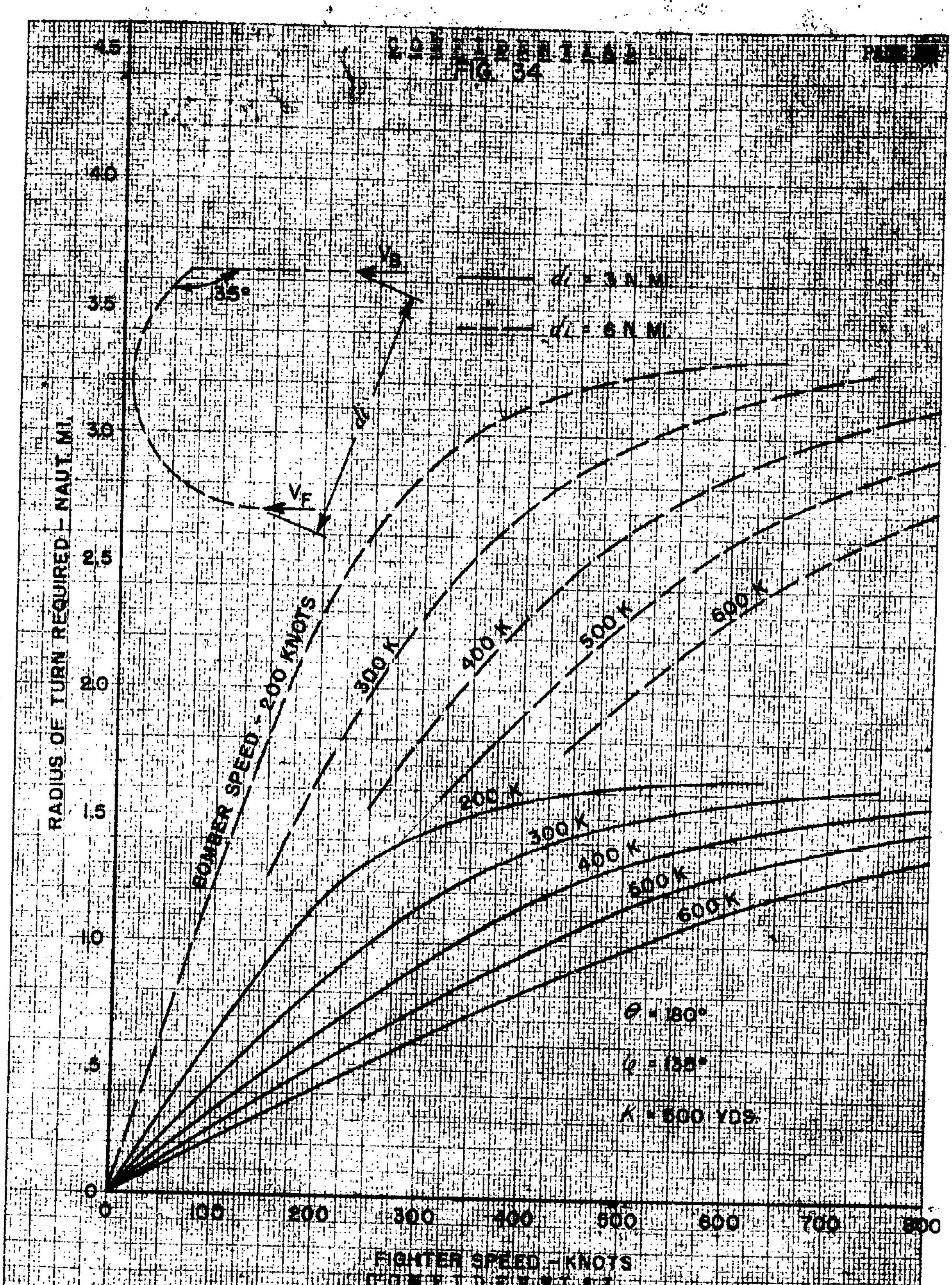
FIG. 34



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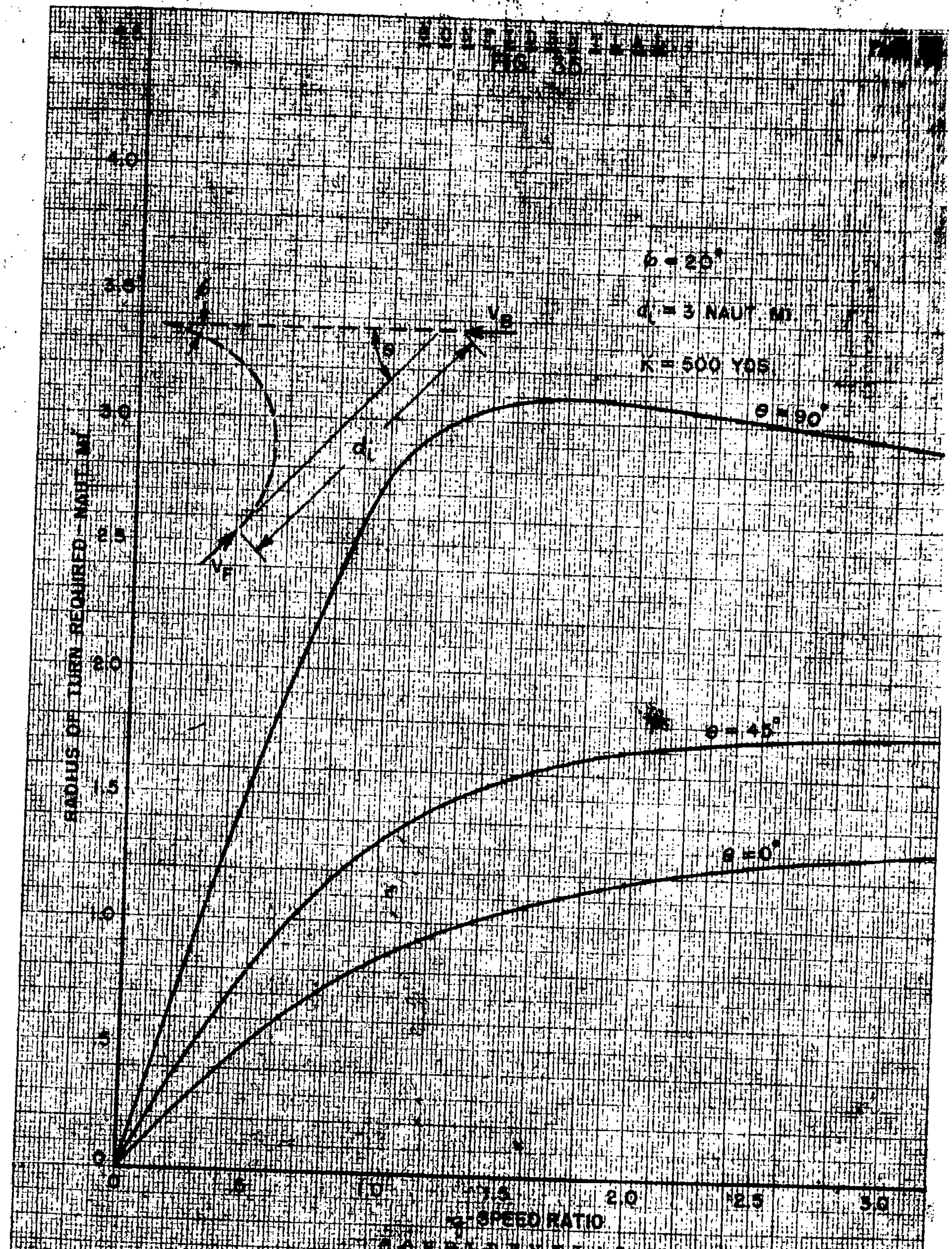
FIG. 35
d_L = 3 NAUT. MI.
K = 500 YDS.
θ = 90°
θ = 45°
θ = 0°
V_B
V_F
d_L
RADIUS OF TURN REQUIRED - NAUT. MI.
SPEED RATIO
0
.5
1.0
1.5
2.0
2.5
3.0
4.0
3.5
CONFIDENTIAL

FIG. 32

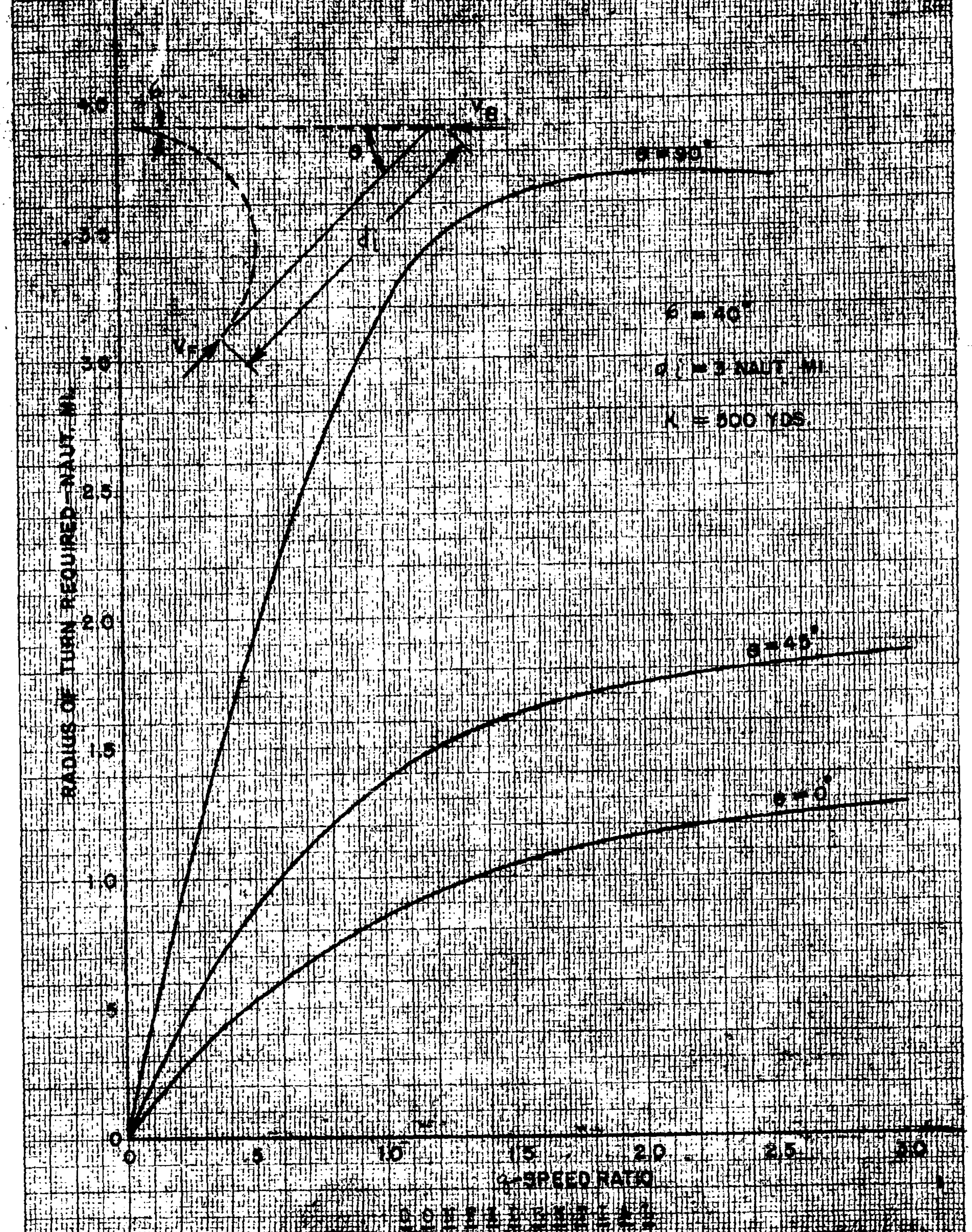
RADIUS OF TURN REQUIRED—NAUT. MI.
α—SPEED RATIO
θ = 90°
θ = 45°
θ = 0°
θ = 40°
d_l = 3 NAUT. MI.
K = 500 YDS.
V_B
V_F
θ
d_l
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

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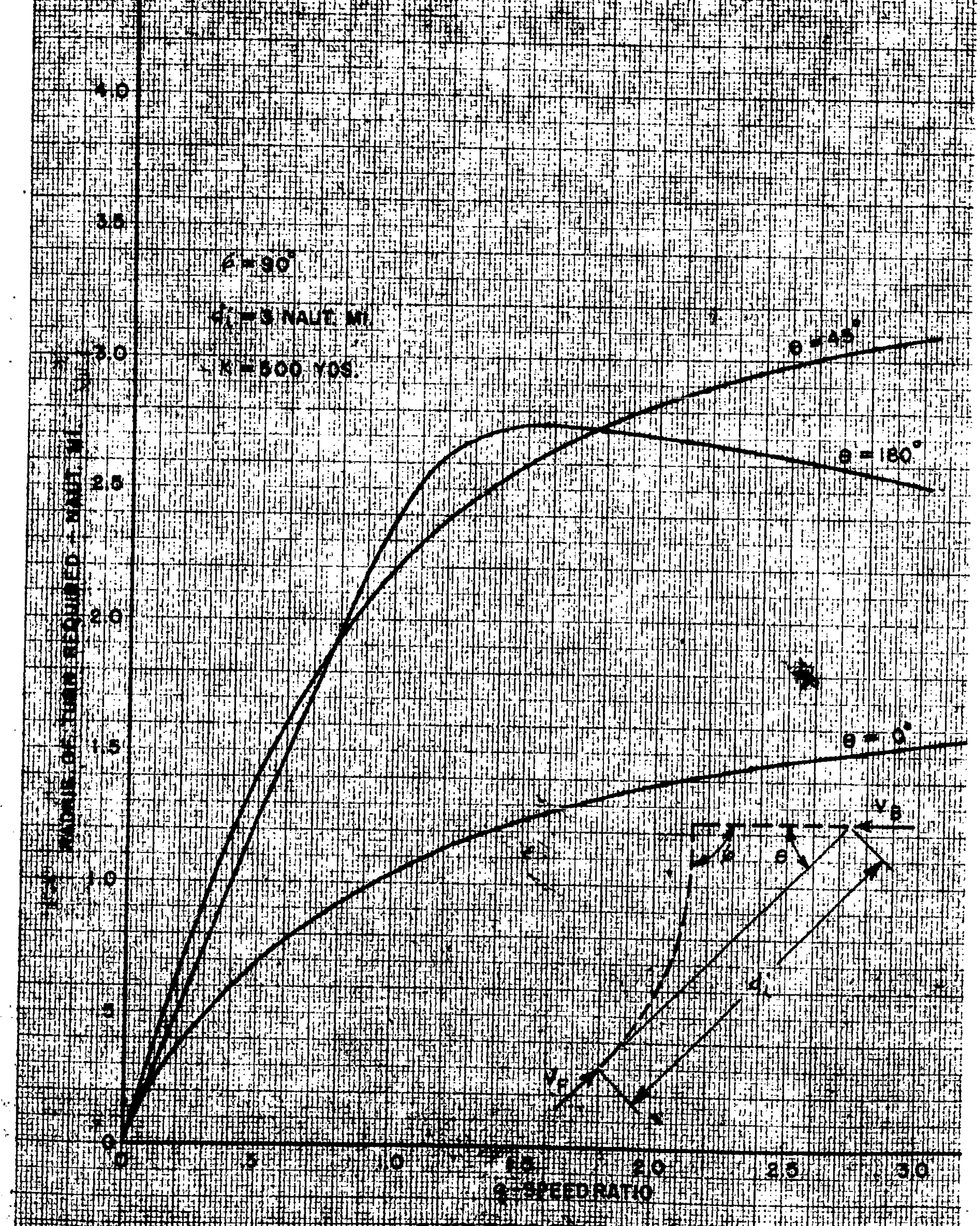
FIG. 57



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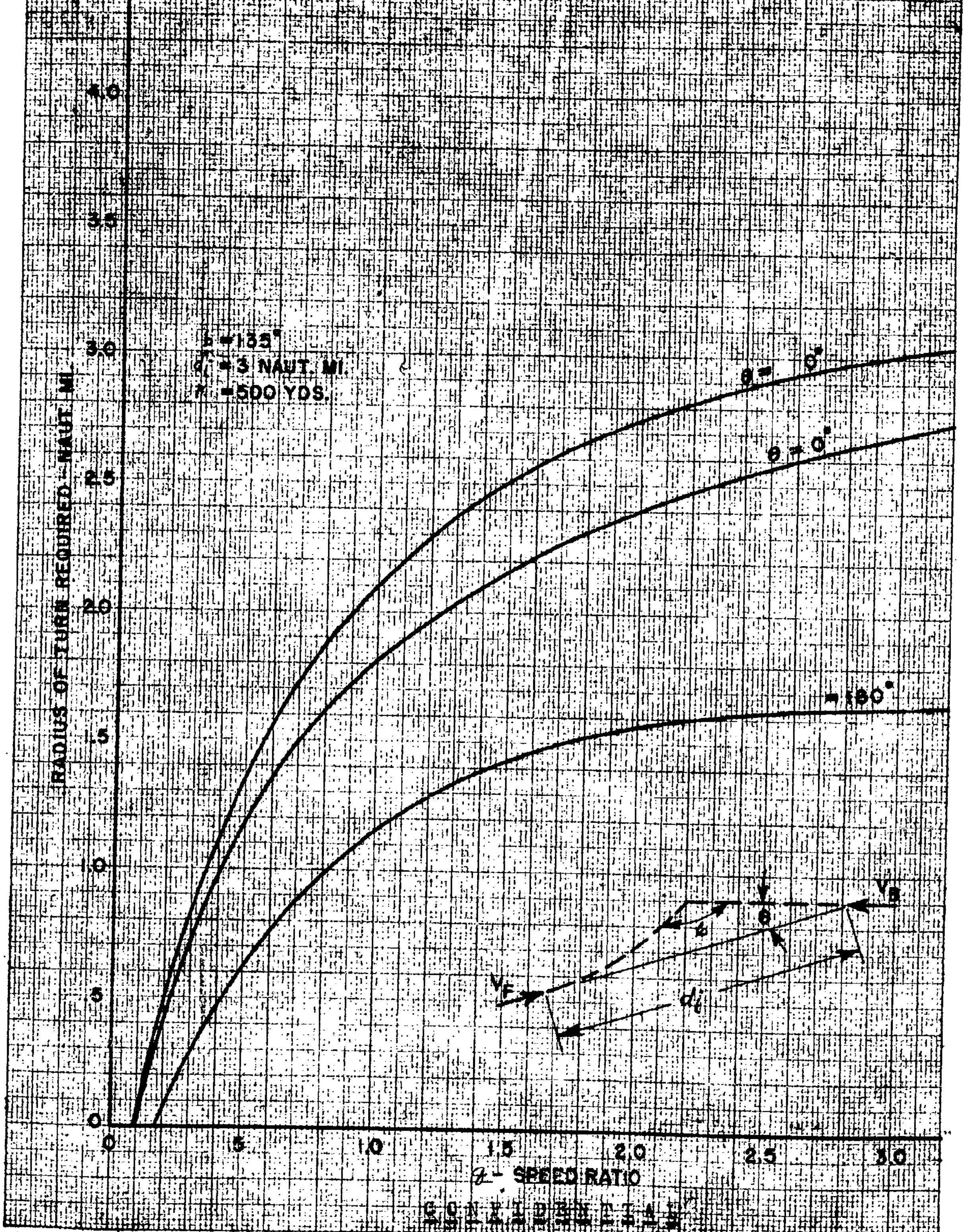
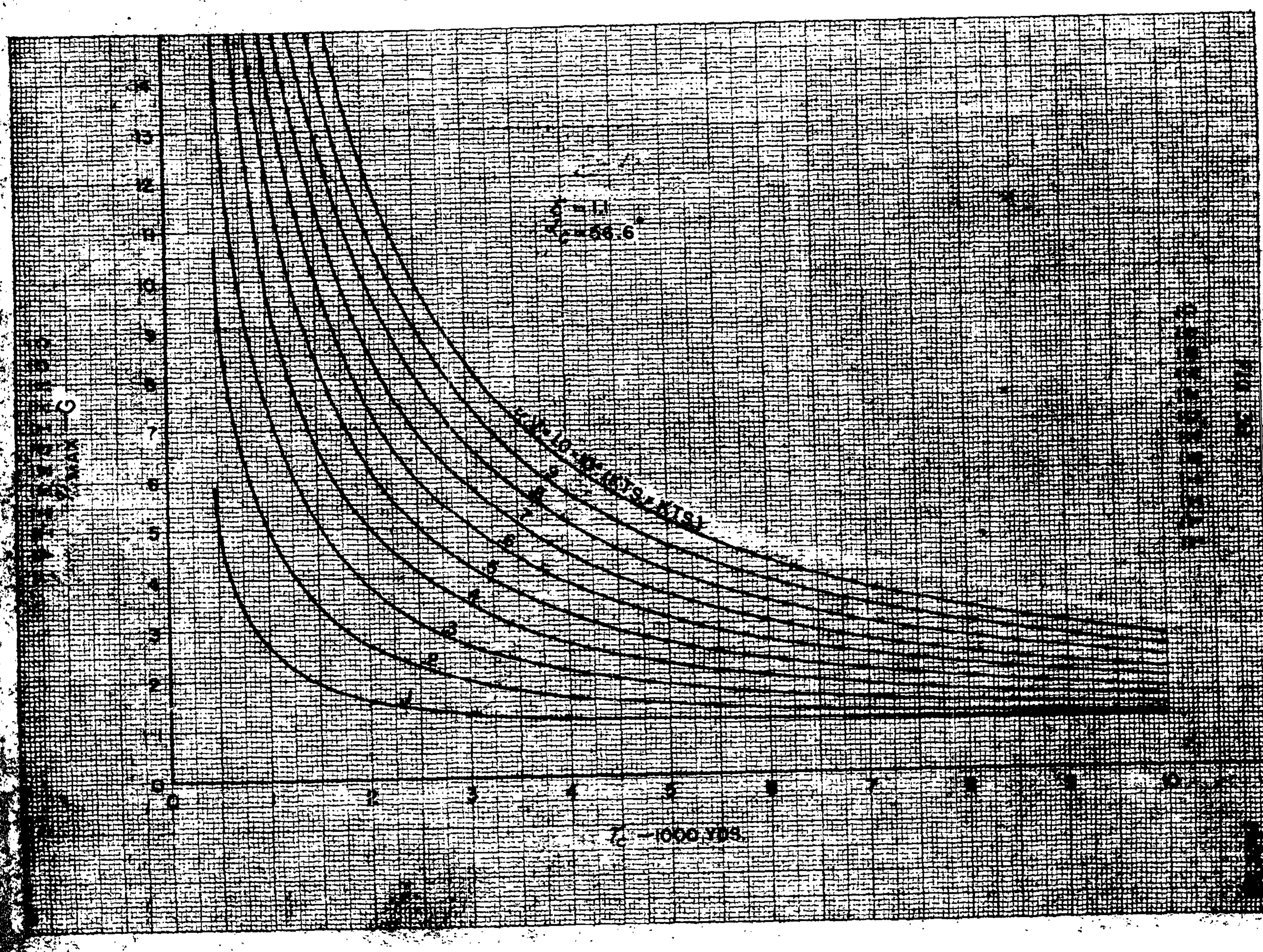

ϕ = 135°
d_i = 3 NAUT. MI.
r = 500 YDS.
θ = 0°
θ = 0°
= 180°
RADIUS OF TURN REQUIRED - NAUT. MI.
β - SPEED RATIO
V_F
V_B
d_i
θ
ϕ

KEUFFEL & ESSER CO., N. Y. NO. 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U. S. A.



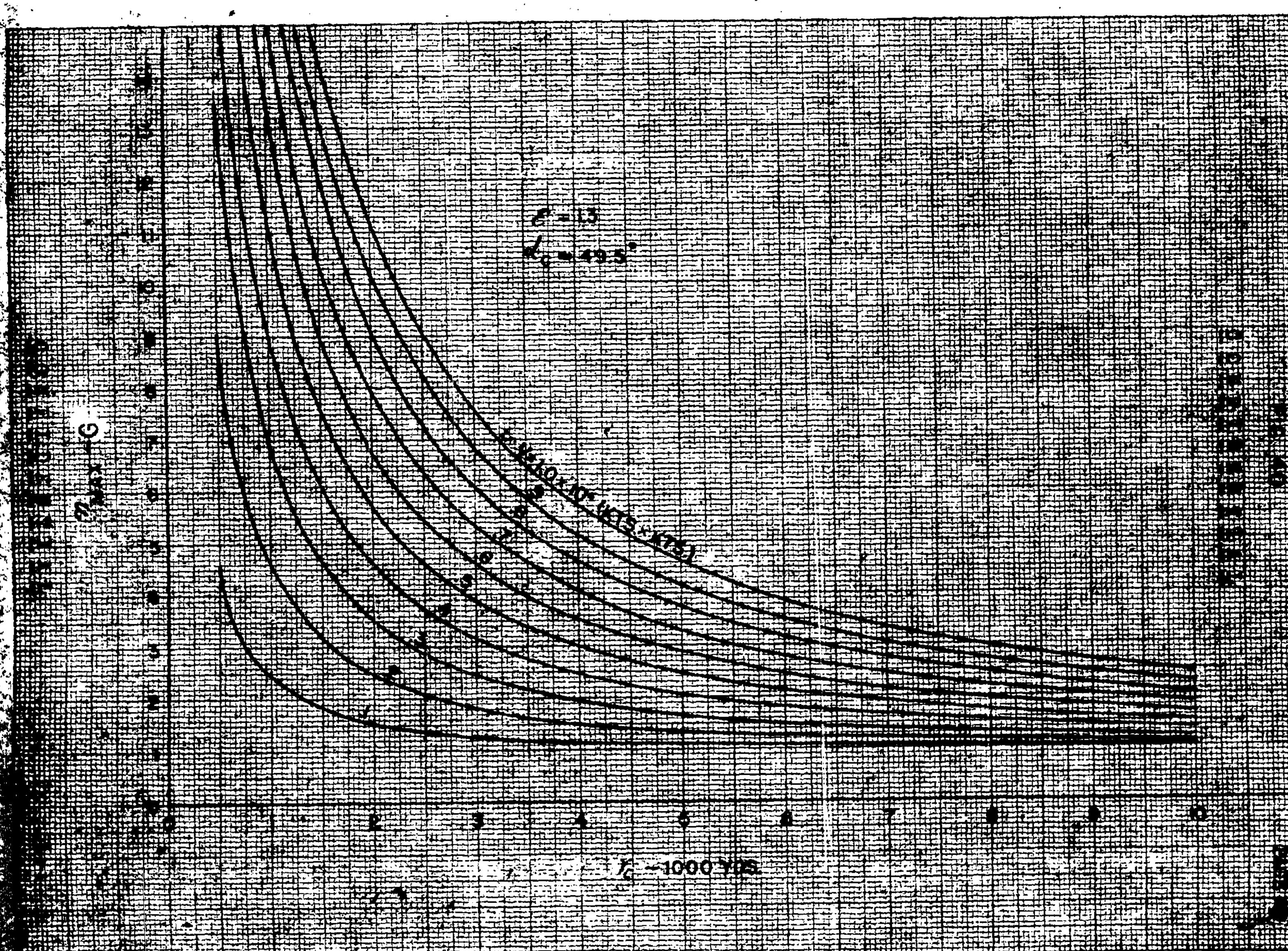

$\epsilon = 13$
$\alpha_c = 49.5°$
$K = 10 \times 10^{6}$ (KTS × KTS)
9
8
7
6
5
4
3
2
1
η_{MAX} — G
r_c — 1000 YDS.
0
1
2
3
4
5
6
7
8
9
10

FIG. 40

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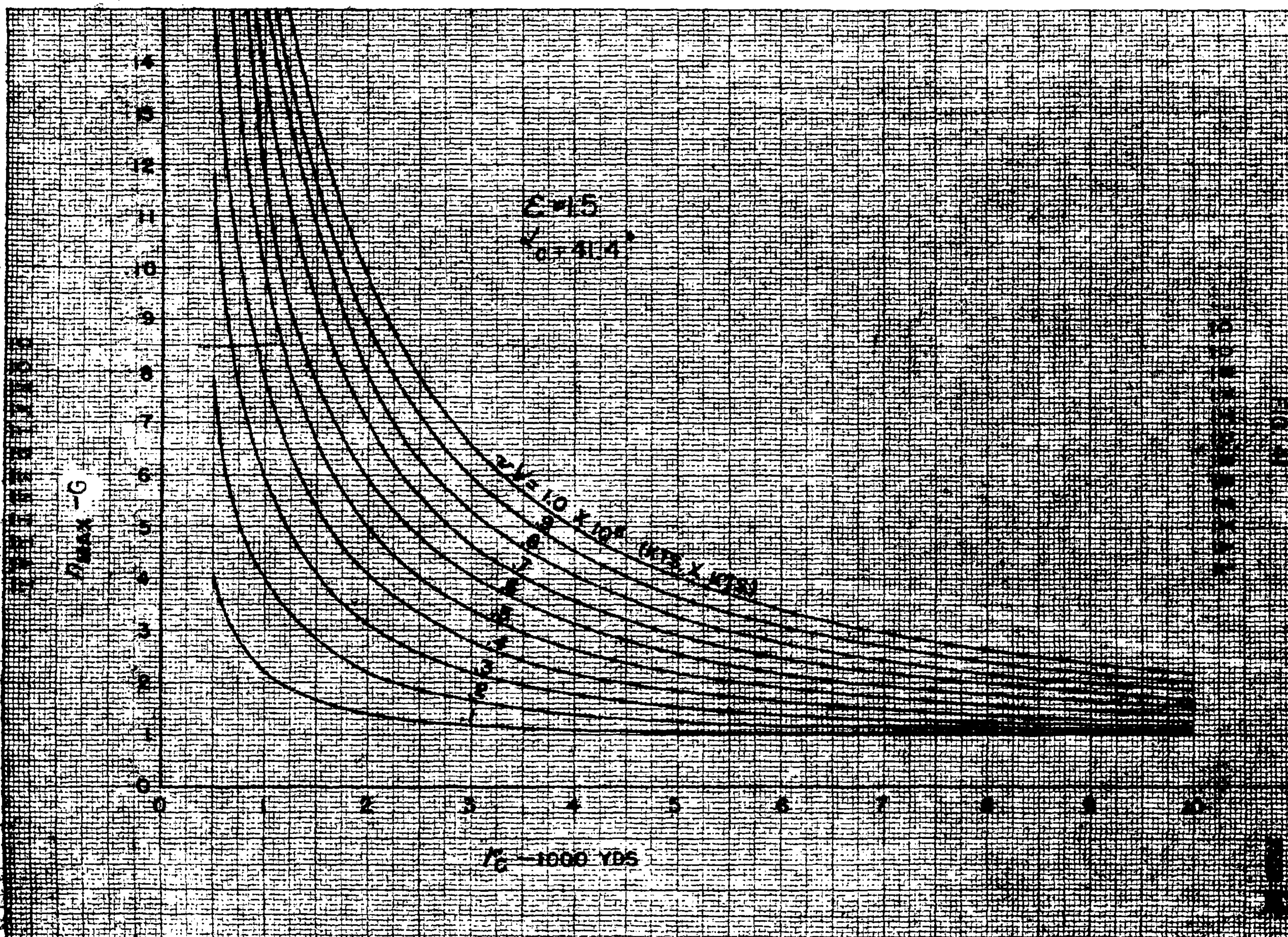
FIG. 41



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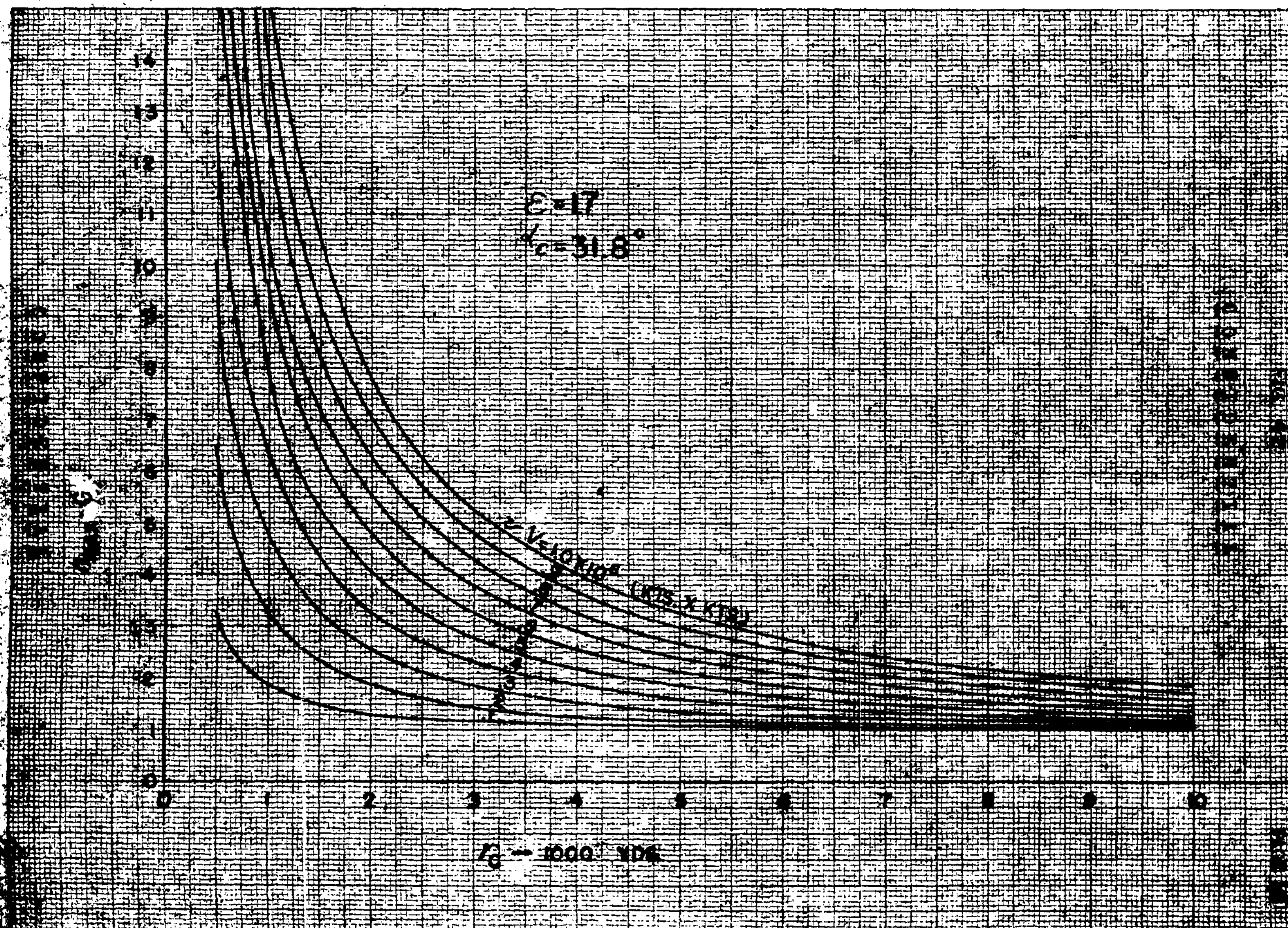
ε = 17
α_c = 31.8°
V = 10 X 10⁶
r_c — 1000' YDS

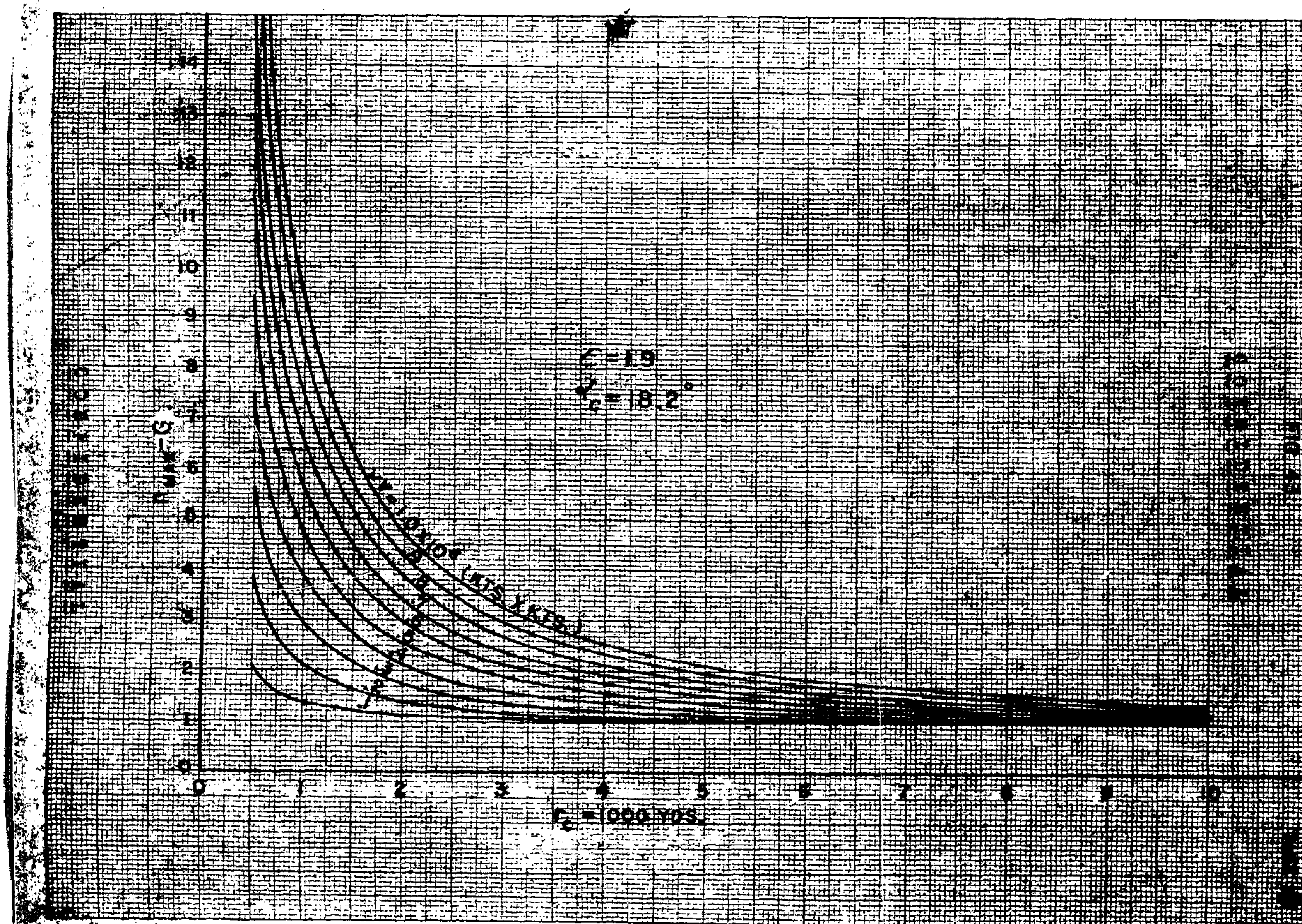
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FIG 43
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$C = 1.9$
$\psi_c = 18.2°$
$V = 10 \times 10^4$ (KTS. X KTS.)
r_c = 1000 YDS.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

APPENDIX I

The following nomenclature, along with those symbols shown on Sketches C, D, and E applies to Figures 22 through 38. These figures, which give the radii of turn required of fighters to meet the illustrated maneuvering problems, are based on computations which required utilization of the equations derived on the following pages:

- c = distance fighter travels before releasing rocket projectile
- d_B = distance bomber travels during time "t"
- d_i = initial distance between bomber and fighter
- K = distance rocket projectile travels
- p = V_F / V_R
- q = V_F / V_B
- R = radius of fighter turn
- t = time lapse between beginning of turn and moment of rocket projectile contact with bomber
- V_B = bomber velocity
- V_F = fighter velocity
- V_R = rocket velocity (assumed to be 1500 knots)
- α = angle through which fighter turns prior to releasing rocket projectile
- θ = angle between initial fighter path direction and the bomber's path
- ϕ = angle between the rocket path and the bomber path

The first group of equations apply to all variations of θ and ϕ .

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$$t = \frac{d_B}{V_B} = \frac{c}{V_F} + \frac{K}{V_R}$$

$$c = \left(\frac{d_B}{V_B} - \frac{K}{V_R}\right) V_F = R\alpha = (q d_B - pK)$$

Referring to Sketch C., where $0^\circ \leq \theta \leq 90^\circ$ and $\theta + \phi \leq 180^\circ$:

$$\theta = 90^\circ - \beta$$
$$\alpha - \beta = 90^\circ - \phi$$
$$\alpha = 180^\circ - \theta - \phi$$
$$\sin\beta = \cos\theta$$
$$\sin(\alpha - \beta) = \cos\phi$$
$$\cos\beta = \sin\theta$$
$$\cos(\alpha - \beta) = \sin\phi$$

$$d_B = d_i \cos\gamma + R\cos\beta - R\cos(\alpha - \beta) + K\cos\phi$$
$$= d_i \cos\gamma + R(\sin\theta - \sin\phi) + K\cos\phi$$
$$h = R[\sin\beta + \sin(\alpha - \beta)] + K\sin\phi$$
$$= R(\cos\theta + \cos\phi) + K\sin\phi$$

$$\sin\gamma = \frac{h}{d_i} \quad ; \quad \cos\gamma = \sqrt{1 - \left(\frac{h}{d_i}\right)^2}$$

$$\cos\gamma = \sqrt{\frac{d_i^2 - [R(\cos\theta + \cos\phi) + K\sin\phi]^2}{d_i^2}}$$

$$d_B = \sqrt{d_i^2 - [R(\cos\theta + \cos\phi) + K\sin\phi]^2} + R(\sin\theta - \sin\phi) + K\cos\phi$$

$$R\alpha = q\left\{\sqrt{d_i^2 - [R(\cos\theta + \cos\phi) + K\sin\phi]^2} + R(\sin\theta - \sin\phi) + K\cos\phi\right\} - pK$$

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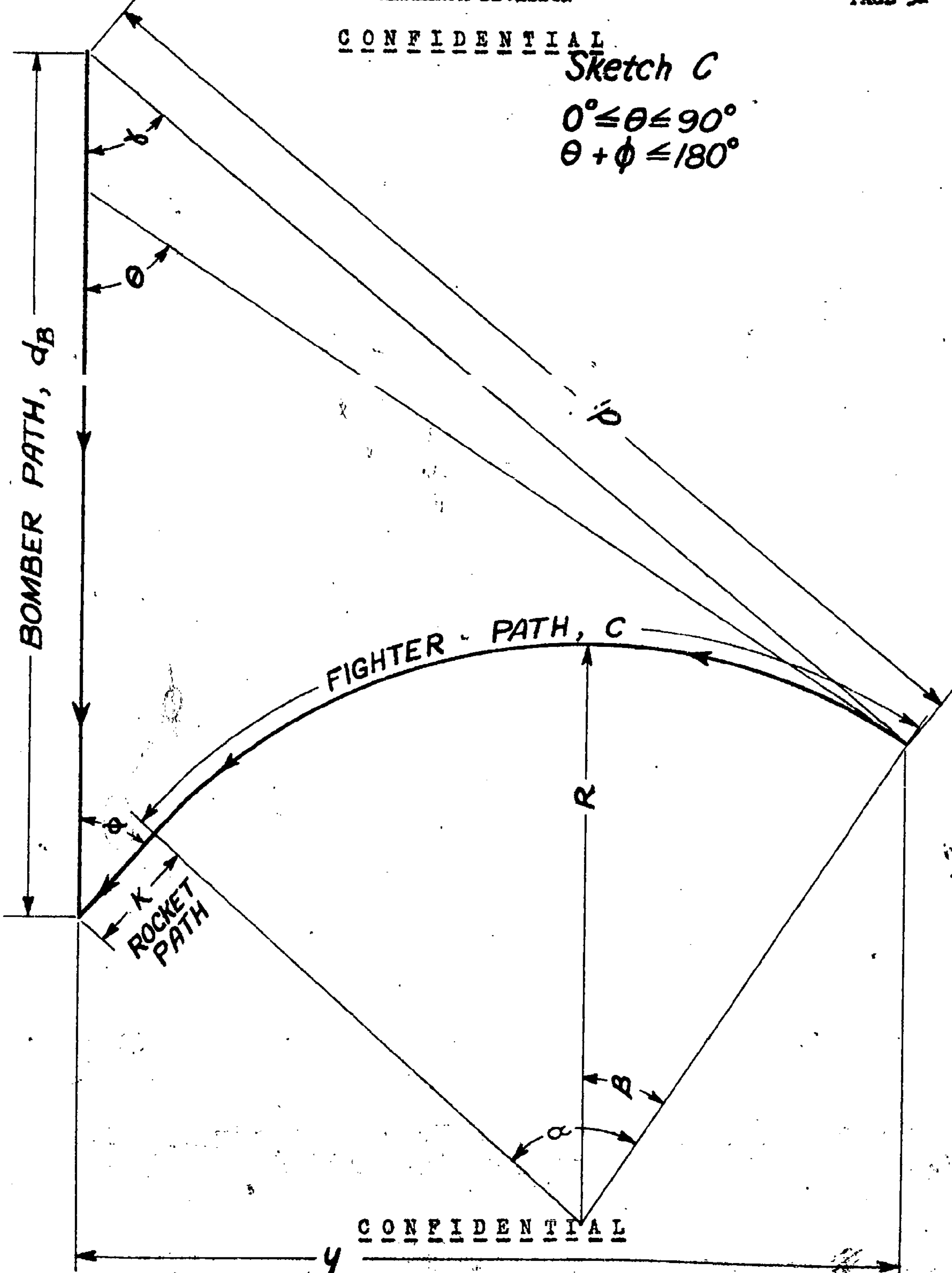
Sketch C

$0^\circ \leq \theta \leq 90^\circ$
$\theta + \phi \leq 180^\circ$



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$$R(\alpha - q\sin\theta + q\sin\phi) - qK\cos\phi + pK$$
$$= q\sqrt{d_i^2 - [R(\cos\theta + \cos\phi) + K\sin\phi]^2}$$

$$R^2(\alpha - q\sin\theta + q\sin\phi)^2 - 2RqK\cos\phi(\alpha - q\sin\theta + q\sin\phi)$$
$$+ 2RpK(\alpha - q\sin\theta + q\sin\phi) + q^2K^2\cos^2\phi$$
$$-2qpK^2\cos\phi + p^2K^2 = q^2d_i^2 - q^2R^2(\cos\theta$$
$$+\cos\phi)^2 - q^2 2R(\cos\theta + \cos\phi)K\sin\phi$$
$$- q^2K^2\sin^2\phi$$

Expressed in the easily solvable simplified quadratic form :

$$\left[(\alpha - q\sin\theta + q\sin\phi)^2 - q^2(\cos\theta + \cos\phi)^2\right]R^2$$
$$+\left[2K\{(p - q\cos\phi)(\alpha - q\sin\theta + q\sin\phi)\right.$$
$$\left. + q^2(\cos\theta + \cos\phi)\sin\phi\}\right]R$$
$$+\left[q^2K^2 + p^2K^2 - 2qpK^2\cos\phi - q^2d_i^2\right] = 0$$

Where: $\alpha = 180° - \theta - \phi$ (expressed in radians)

and $0 \leq \theta \leq 90°$ & $\theta + \phi \leq 180°$

Referring to Sketch D , where $90° \leq \theta \leq 180°$ and $\theta + \phi \geq 180°$:

$$\theta' = 90° - \beta$$
$$\alpha - \beta = 90° - \phi'$$
$$\alpha = 180° - \phi' - \theta'$$
$$\sin\beta = \cos\theta'$$
$$\sin(\alpha - \beta) = \cos\phi'$$
$$\cos\beta = \sin\theta'$$
$$\cos(\alpha - \beta) = \sin\phi'$$

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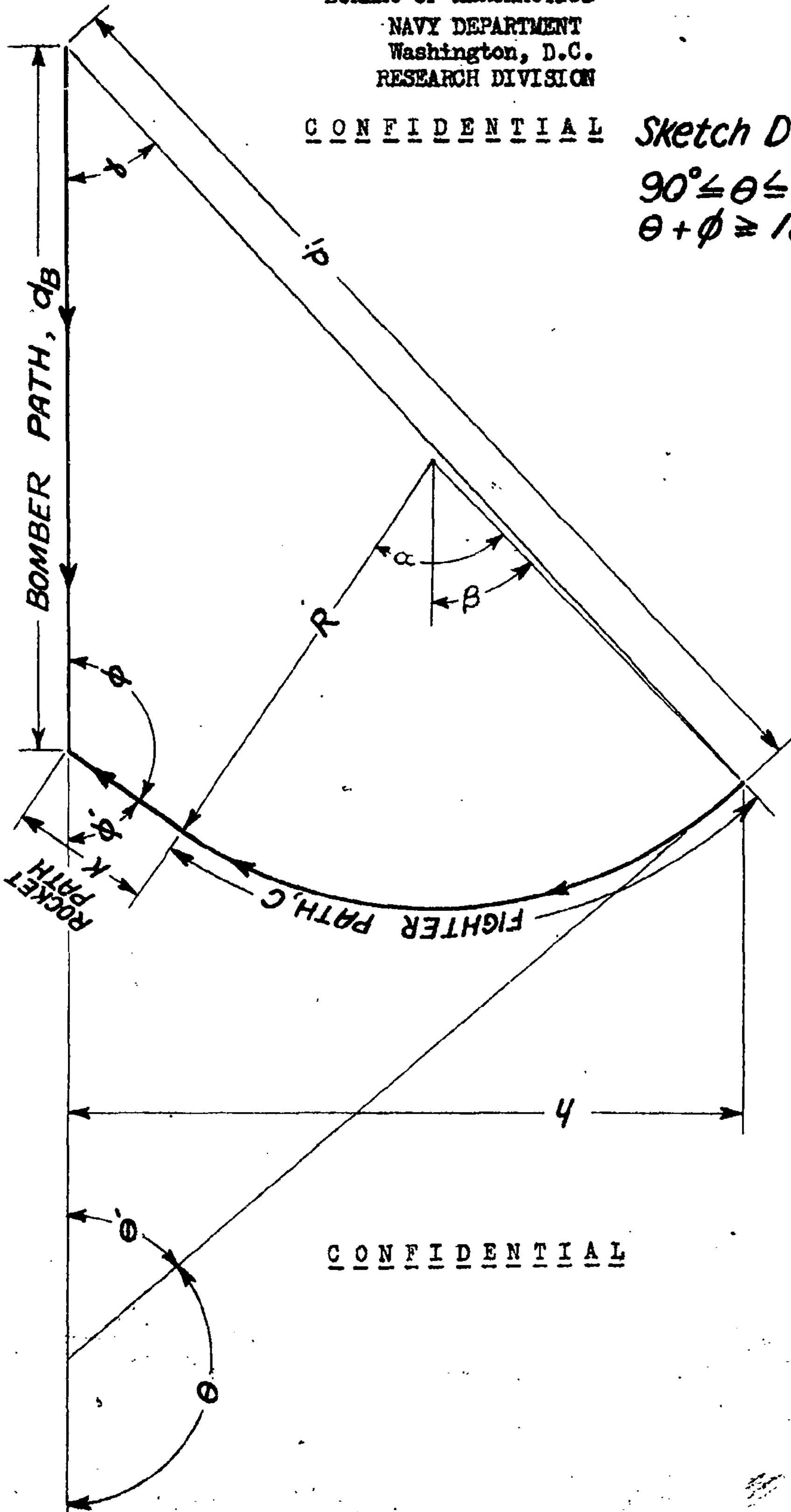
Sketch D

$90° \leq \theta \leq 180°$
$\theta + \phi \geq 180°$



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$$h = R[\sin\beta + \sin(\alpha-\beta)] + K\sin\phi'$$
$$= R(\cos\theta' + \cos\phi') + K\sin\phi'$$
$$d_B = d_i\cos\gamma + R[\cos(\alpha-\beta) - \cos\beta] - K\cos\phi'$$
$$= d_i\cos\gamma + R(\sin\phi' - \sin\theta') - K\cos\phi'$$

$$\sin\gamma = \frac{h}{d_i} \quad ; \quad \cos\gamma = \sqrt{1-\left(\frac{h}{d_i}\right)^2}$$

$$\cos\gamma = \sqrt{\frac{d_i^2 - [R(\cos\theta' + \cos\phi') + K\sin\phi']^2}{d_i^2}}$$

$$d_B = \sqrt{d_i^2 - [R(\cos\theta' + \cos\phi') + K\sin\phi']^2}$$
$$+ R(\sin\phi' - \sin\theta') - K\cos\phi'$$

$$R\alpha = q\Big\{\sqrt{d_i^2 - [R(\cos\theta' + \cos\phi') + K\sin\phi']^2}$$
$$+ R(\sin\phi' - \sin\theta') - K\cos\phi'\Big\} - pK$$

$$R(\alpha - q\sin\phi' + q\sin\theta) + qK\cos\phi' + pK$$
$$= q\sqrt{d_i^2 - [R(\cos\theta' + \cos\phi') + K\sin\phi']^2}$$

$$R^2(\alpha - q\sin\phi' + q\sin\theta)^2 + 2RqK\cos\phi'(\alpha - q\sin\phi' + q\sin\theta)$$
$$2RpK(\alpha - q\sin\phi' + q\sin\theta') + q^2K^2\cos^2\phi'$$
$$+ 2qpK^2\cos\phi' + p^2K^2 - q^2d_i^2$$
$$- q^2R^2(\cos\theta' + \cos\phi)^2 - 2q^2R(\cos\theta + \cos\phi)K\sin\phi$$
$$- q^2K^2\sin^2\phi'$$

This equation is given in the simplified quadratic form on the following page:

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$$\left[(\alpha - q\sin\phi' + q\sin\theta')^2 + q^2(\cos\theta' + \cos\phi')^2\right]R^2$$
$$+\left[2K\{(p+q\cos\phi')(\alpha - q\sin\phi + q\sin\theta)\right.$$
$$\left.+\,q^2(\cos\theta' + \cos\phi')\sin\phi'\}\right]R$$
$$+\left[q^2K^2 + p^2K^2 + 2qpK^2\cos\phi' - q^2d_i^2\right] = 0.$$

$$\theta' = 180^\circ - \theta \qquad \phi' = 180^\circ - \phi$$
$$\sin\theta' = \sin\theta \qquad \sin\phi' = \sin\phi$$
$$\cos\theta' = -\cos\theta \qquad \cos\phi' = -\cos\phi$$
$$\alpha = 180^\circ - \phi' - \theta' = \theta + \phi - 180^\circ$$

Therefore:

$$\left[(\alpha - q\sin\phi + q\sin\theta)^2 + q^2(\cos\theta + \cos\phi)^2\right]R^2$$
$$+\left[2K\{(p - q\cos\phi)(\alpha - q\sin\phi + q\sin\theta)\right.$$
$$\left.-\,q^2(\cos\theta + \cos\phi)\sin\phi\}\right]R$$
$$+\left[qK^2 + p^2K^2 - 2qpK^2\cos\phi - q^2d_i^2\right] = 0$$

Where: $\alpha = \theta + \phi - 180^\circ$ (expressed in radians)
and $90^\circ \leq \theta \leq 180^\circ$ & $\theta + \phi \geq 180^\circ$

Referring to Sketch E, where $\theta = 0^\circ$ and $\phi = 180^\circ$ and the fighter makes two 90° turns ($\alpha = \pi$):

$$d_B = d_i\cos\gamma - K - 2R$$

$$\sin\gamma = \frac{2R}{d_i} \qquad \cos\gamma = \sqrt{1 - \left(\frac{2R}{d_i}\right)^2}$$

$$d_B = \sqrt{d_i^2 - 4R^2} - K - 2R$$

$$\frac{R\alpha}{q} = \sqrt{d_i^2 - 4R^2} - K - 2R - \frac{pK}{q}$$

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$$R\left(\frac{\alpha}{q}+2\right)+K\left(1+\frac{p}{q}\right)=\sqrt{d_i^2-4R^2}$$

$$R^2\left(\frac{\alpha}{q}+2\right)^2+2RK\left(\frac{\alpha}{q}+2\right)\left(1+\frac{p}{q}\right)+K^2\left(1+\frac{p}{q}\right)^2=d_i^2-4R^2$$

Expressed in a simplified quadratic form:

$$\left[\left(\frac{\alpha}{q}+2\right)^2+4\right]R^2+\left[2K\left(\frac{\alpha}{q}+2\right)\left(1+\frac{p}{q}\right)\right]R$$
$$+\left[K^2\left(1+\frac{p}{q}\right)^2-d_i^2\right]=0$$

Where: $\alpha=\pi$, $\theta=0^\circ$; and $\phi=180^\circ$

Inspection of the equations derived above will reveal that "p" is of little significance in the determination of "R" for the values of d_i, K, and V_F which have been considered in this report. Even though figures 35 through 38 are only exactly correct for p = 0.1, errors resulting from the use of these figures when $p \neq 0.1$ will be inconsequential for practical values of "V_F" and "q".

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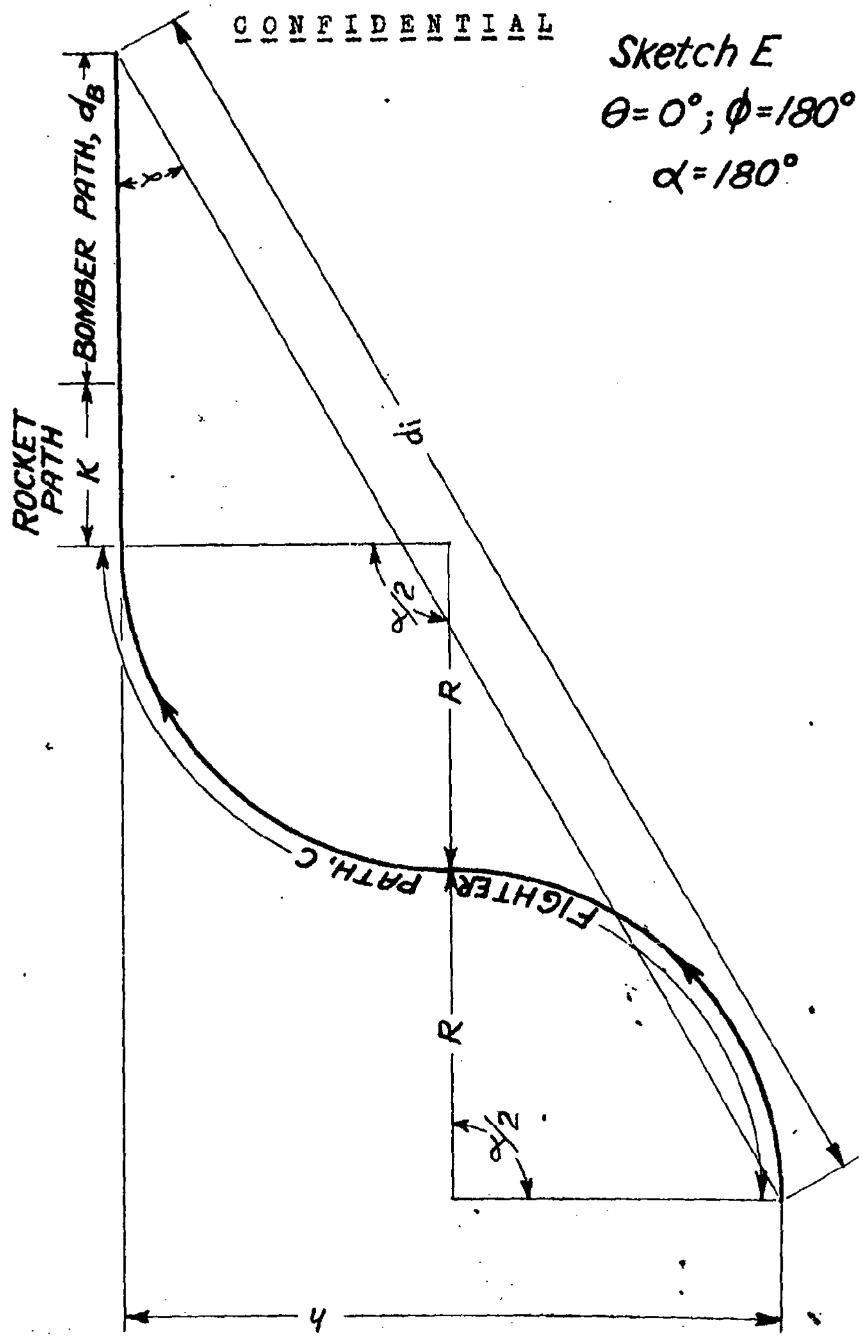
C O N F I D E N T I A L

Sketch E
$\theta = 0°; \phi = 180°$
$\alpha = 180°$



C O N F I D E N T I A L

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APPENDIX II

Reference(1)is the source for the several equations used to compute the data upon which Figures 39 through 43 are based. These equations, which follow immediately, refer to sketch F, and accompanying nomenclature.

$$\alpha_c = \cos^{-1}\frac{\varepsilon}{2}$$

$$r_c = r_T(\sin\alpha_c)^{\varepsilon-1}\cdot(1+\cos\alpha_c)^{-\varepsilon}$$

$$n_{t_{MAX}} = \frac{vV}{Gr_T}\left(1+\frac{\varepsilon}{2}\right)^{1+\frac{\varepsilon}{2}}\cdot\left(1-\frac{\varepsilon}{2}\right)^{1-\frac{\varepsilon}{2}}$$

SUBSTITUTING:

$$n_{t_{MAX}} = \frac{vV}{Gr_c}\left(1+\frac{\varepsilon}{2}\right)^{1+\frac{\varepsilon}{2}}\left(1-\frac{\varepsilon}{2}\right)^{1-\frac{\varepsilon}{2}}(\sin\alpha_c)^{\varepsilon-1}(1+\cos\alpha_c)^{-\varepsilon}$$

Reference (1) also contains equations which may be used to compute the time required for a fighter following a pursuit path to intercept its target, if the initial range, r, and azimuth angle, α, are known

$$r_T = \frac{r\sin\alpha}{\left(\tan\frac{\alpha}{2}\right)^{\varepsilon}}$$

$$t = \frac{r_T}{2V}\left[\frac{\left(\tan\frac{\alpha}{2}\right)^{\varepsilon-1}}{\varepsilon-1} + \frac{\left(\tan\frac{\alpha}{2}\right)^{\varepsilon+1}}{\varepsilon+1}\right]$$

$$= \frac{r\sin\alpha}{2V\left(\tan\frac{\alpha}{2}\right)^{\varepsilon}}\left[\frac{\left(\tan\frac{\alpha}{2}\right)^{\varepsilon-1}}{\varepsilon-1} + \frac{\left(\tan\frac{\alpha}{2}\right)^{\varepsilon+1}}{\varepsilon+1}\right]$$

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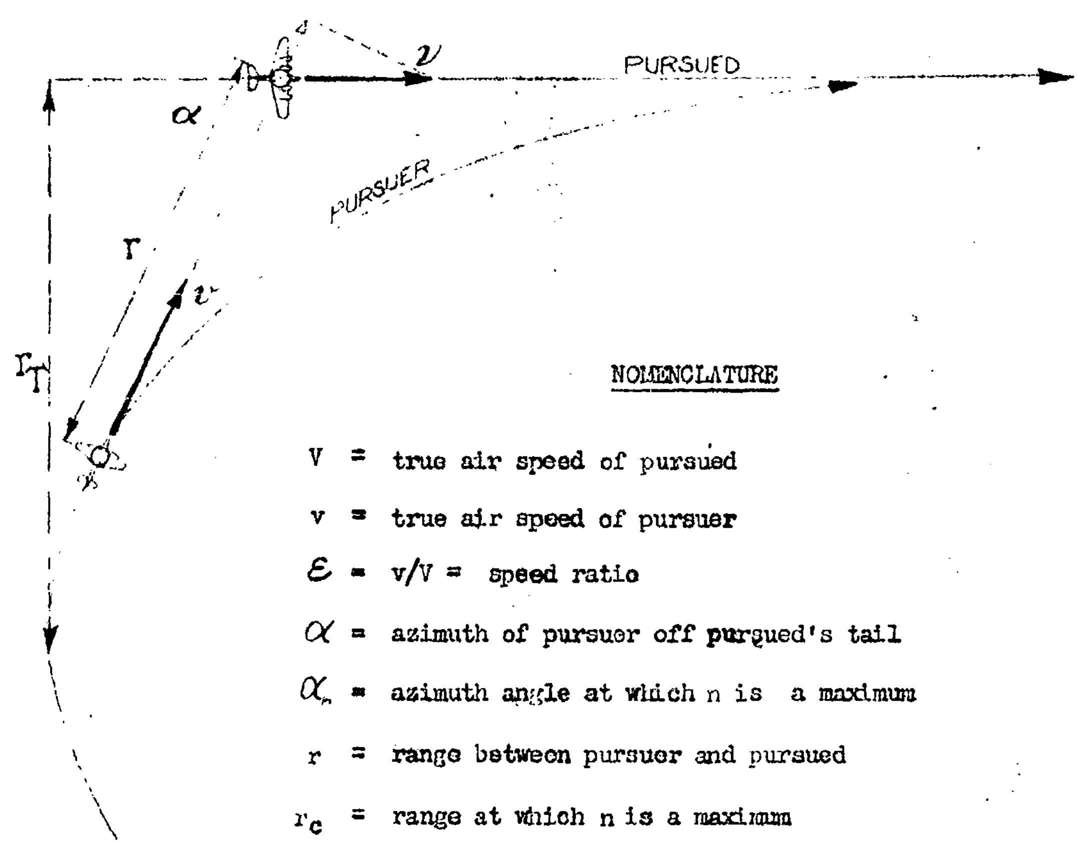
SKETCH F



NOMENCLATURE

V = true air speed of pursued

v = true air speed of pursuer

$\mathcal{E}$ = v/V = speed ratio

α = azimuth of pursuer off pursued's tail

α_n = azimuth angle at which n is a maximum

r = range between pursuer and pursued

r_c = range at which n is a maximum

r_T = range at which pursuer is headed at right angles to flight path of pursued.

n_η = horizontal load factor - G

n = wing load factor - G

G = gravitational acceleration

t = time required for pursuer to intercept pursued

The preceding equations (and therefore Figures 39 through 43) are only applicable to a non-lead pursuit path.

C O N F I D E N T I A L

REFERENCE

1. Klemper, W. B. : "Interception and Escape Techniques at High Speed and High Altitude," Douglas Aircraft Company Report No. SM-3263, dtd October 1941

C O N F I D E N T I A L

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE OHIO

FEB 19 2002

MEMORANDUM FOR DTIC/OCQ (ZENA ROGERS)
8725 JOHN J. KINGMAN ROAD, SUITE 0944
FORT BELVOIR VA 22060-6218

FROM: AFMC CSO/SCOC
4225 Logistics Avenue, Room S132
Wright-Patterson AFB OH 45433-5714

SUBJECT: Technical Reports Cleared for Public Release

References: (a) HQ AFMC/PAX Memo, 26 Nov 01, Security and Policy Review, AFMC 01-242 (Atch 1)

(b) HQ AFMC/PAX Memo, 19 Dec 01, Security and Policy Review, AFMC 01-275 (Atch 2)

(c) HQ AFMC/PAX Memo, 17 Jan 02, Security and Policy Review, AFMC 02-005 (Atch 3)

1. Technical reports submitted in the attached references listed above are cleared for public release in accordance with AFI 35-101, 26 Jul 01, *Public Affairs Policies and Procedures*, Chapter 15 (Cases AFMC 01-242, AFMC 01-275, & AFMC 02-005).

2. Please direct further questions to Lezora U. Nobles, AFMC CSO/SCOC, DSN 787-8583.

Lezora U. Nobles

LEZORA U. NOBLES
AFMC STINFO Assistant
Directorate of Communications and Information

Attachments:
1. HQ AFMC/PAX Memo, 26 Nov 01
2. HQ AFMC/PAX Memo, 19 Dec 01
3. HQ AFMC/PAX Memo, 17 Jan 02

cc:
HQ AFMC/HO (Dr. William Elliott)

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE OHIO

JAN 17 2002

MEMORANDUM FOR HQ AFMC/HO

FROM: HQ AFMC/PAX

SUBJECT: Security and Policy Review, AFMC 02-005

1. The reports listed in your attached letter were submitted for security and policy review IAW AFI 35-101, Chapter 15. They have been cleared for public release.

2. If you have any questions, please call me at 77828. Thanks.

James A. Morrow

JAMES A. MORROW
Security and Policy Review
Office of Public Affairs

Attachment:
Your Ltr 14 January 2002

14 January 2002

MEMORANDUM FOR: HQ AFMC/PAX
Attn: Jim Morrow

FROM: HQ AFMC/HO

SUBJECT: Releasability Reviews

1. Please conduct public releasability reviews for the following attached Defense Technical Information Center (DTIC) reports:

   a. *Flight Test Program for Model P-86 Airplane Class – Jet Propelled Fighter*, 2 December 1946; DTIC No. AD-B804 069.

   b. *Physiological Recognition of Strain in Flying Personnel: Eosinopenia in F-86 Combat Operations*, September 1953; DTIC No. AD- 020 375.

   c. *Phase IV Performance Test of the F-86F-40 Airplane Equipped with 6x3-inch Leading Edge Slats and 12-inch Extensions on the Wing Tips*, May 1956; DTIC No. AD- 096 084.

   d. *F-86E Thrust Augmentation Evaluation*, March 1957; DTIC No. AD- 118 703.

   e. *F-86E Thrust Augmentation Evaluation*, Appendix IV, March 1957; DTIC No. AD- 118 707.

   f. *A Means of Comparing Fighter Effectiveness in the Approach Phase*, October 1949; DTIC No. AD- 223 596.

   g. *War Emergency Thrust Augmentation for the J47 Engine in the F-86 Aircraft*, August 1955; DTIC No. AD- 095 757.

   h. *Operational Suitability Test of the F-86F Airplane*, 4 May 1953; DTIC No. AD- 017 568.

   i. *Estimated Aerodynamic Characteristics for Design of the F-86E Airplane*, 26 December 1950; DTIC No. AD- 069 271.

   j. *Combat Suitability Test of F-86F-2 Aircraft with T-160 Guns*, August 1953; DTIC No. AD- 019 725.

2. These attachments have been requested by Dr. Kenneth P. Werrell, a private researcher.

3. The AFMC/HO point of contact for these reviews is Dr. William Elliott, who may be reached at extension 77476.

JOHN D. WEBER
Command Historian

10 Attachments:
a. DTIC No. AD-B804 069
b. DTIC No. AD- 020 375
c. DTIC No. AD- 096 084
d. DTIC No. AD- 118 703
e. DTIC No. AD- 118 707
f. DTIC No. AD- 223 596
g. DTIC No. AD- 095 757
h. DTIC No. AD- 017 568
i. DTIC No. AD- 069 271
j. DTIC No. AD- 019 725